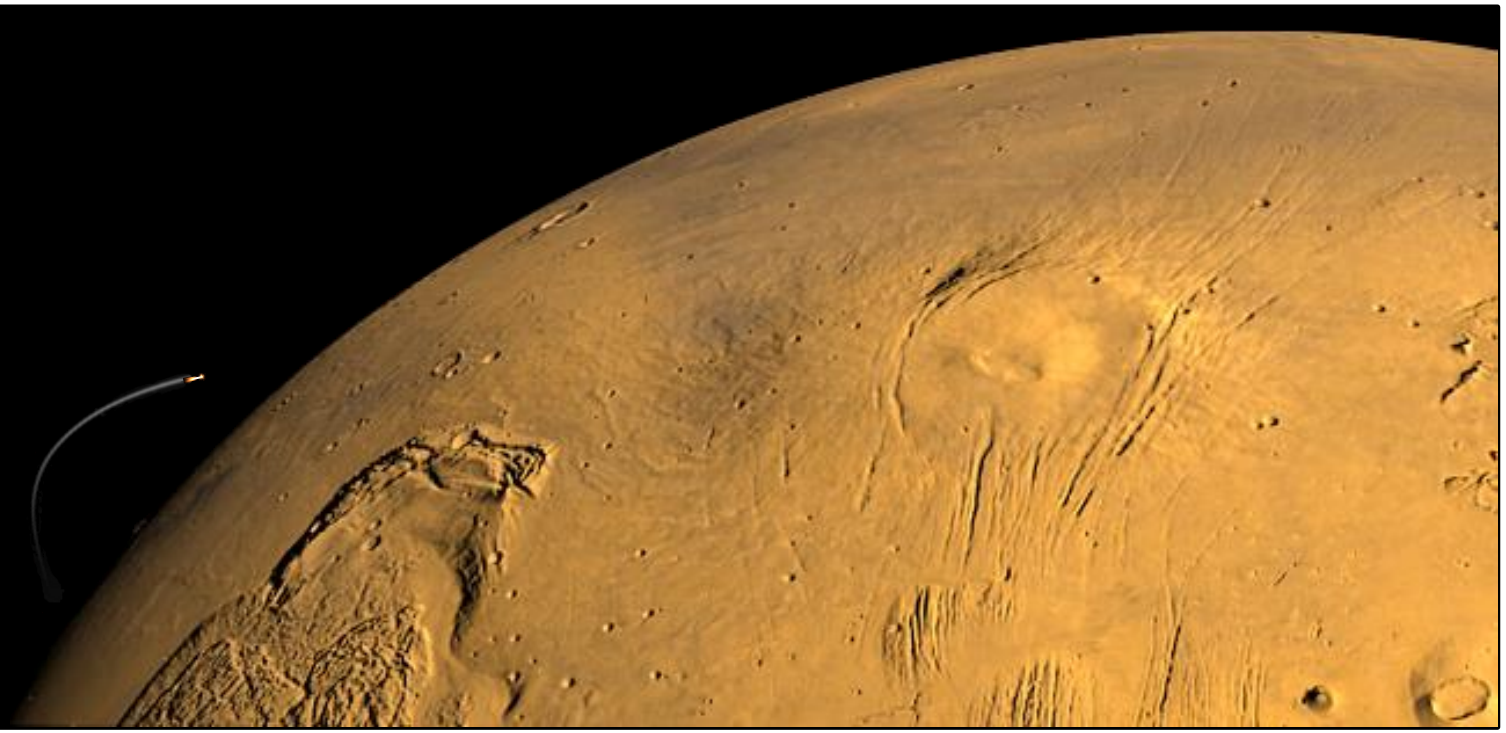
Mars Ascent Vehicle



Jet Propulsion Laboratory
California Institute of Technology

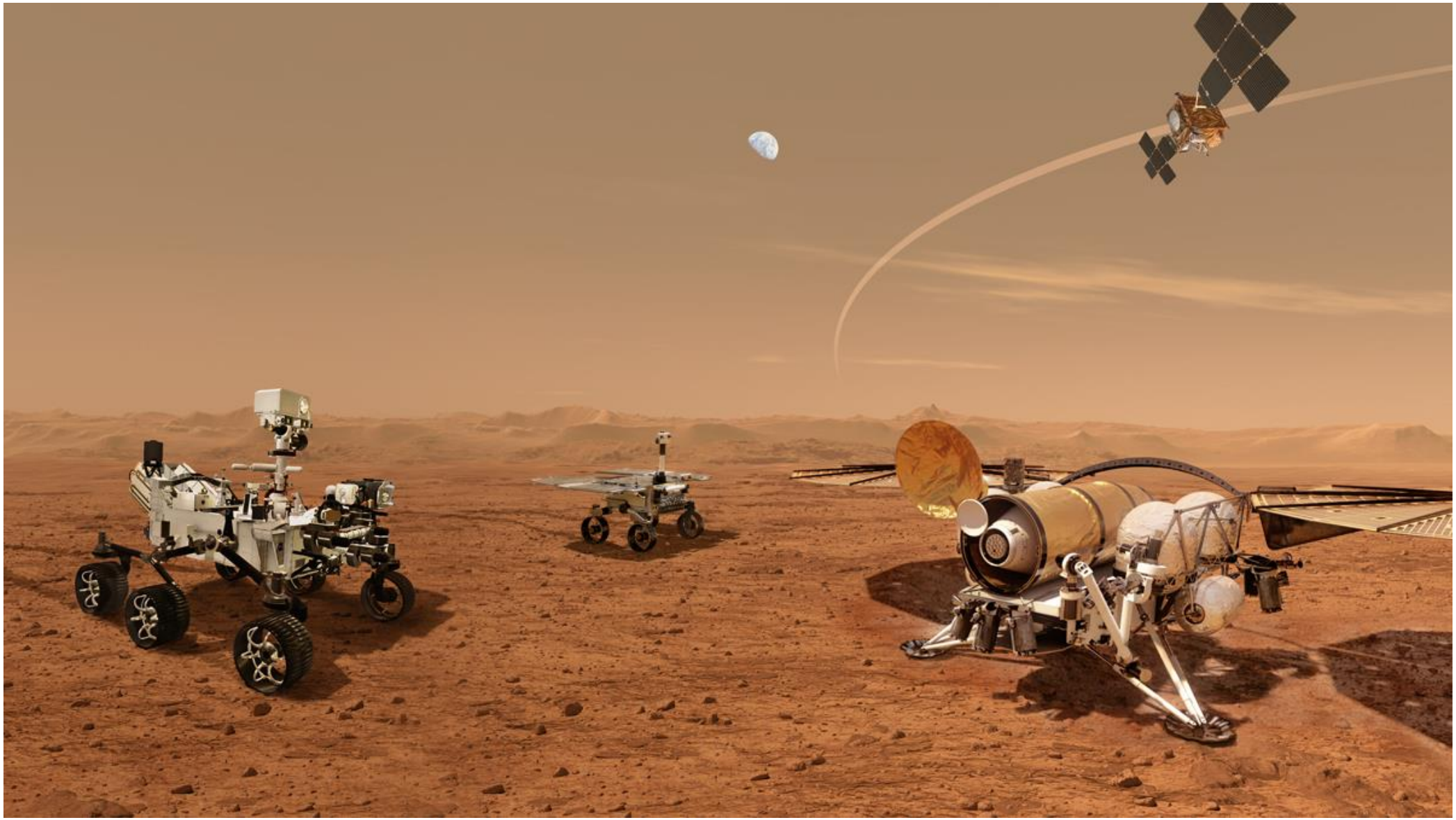
MARSHALL
SPACE FLIGHT CENTER

The Mars Ascent Vehicle & Model-Based Systems Engineering

Isabeta Rountree (MSFC-EV71) ESSCA
April 2022

Sev1Tech LLC | Jacobs Space Exploration Group | ESSCA Contract
NASA Marshall Space Flight Center
Auburn University & JBS Solutions Presentations

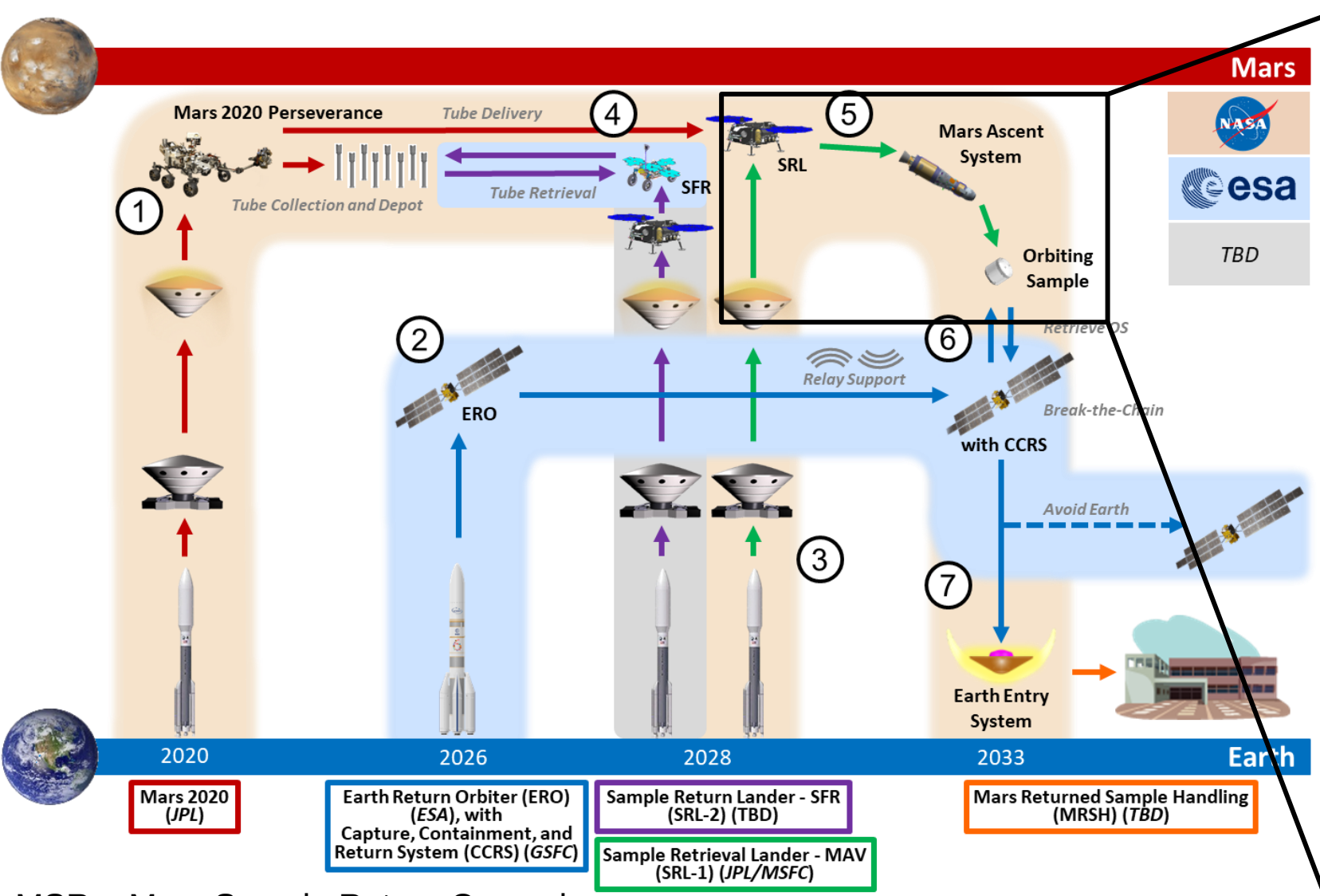
Mars Ascent Vehicle (MAV) Overview

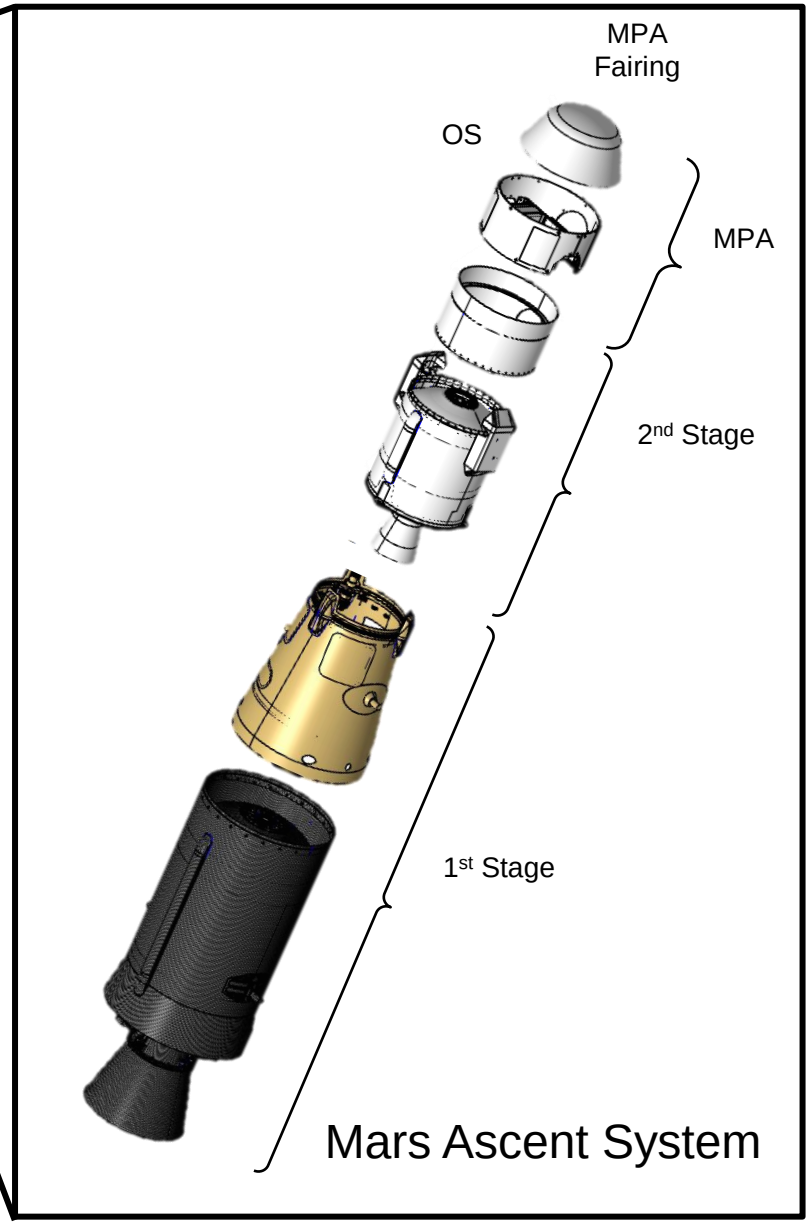


*Images notional and subject to change

MSR Campaign ConOps & MAS

National Aeronautics and Space Administration
Jet Propulsion Laboratory / Marshall Space Flight Center
Mars Sample Return / Mars Ascent Vehicle





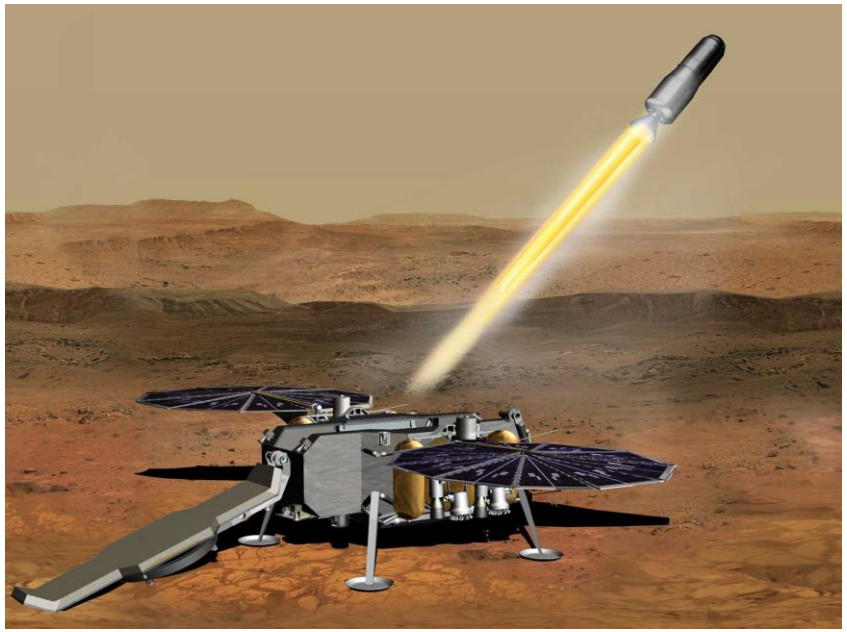
MSR – Mars Sample Return Campaign
MAS – Mars Ascent System
ConOps – Concept of Operations

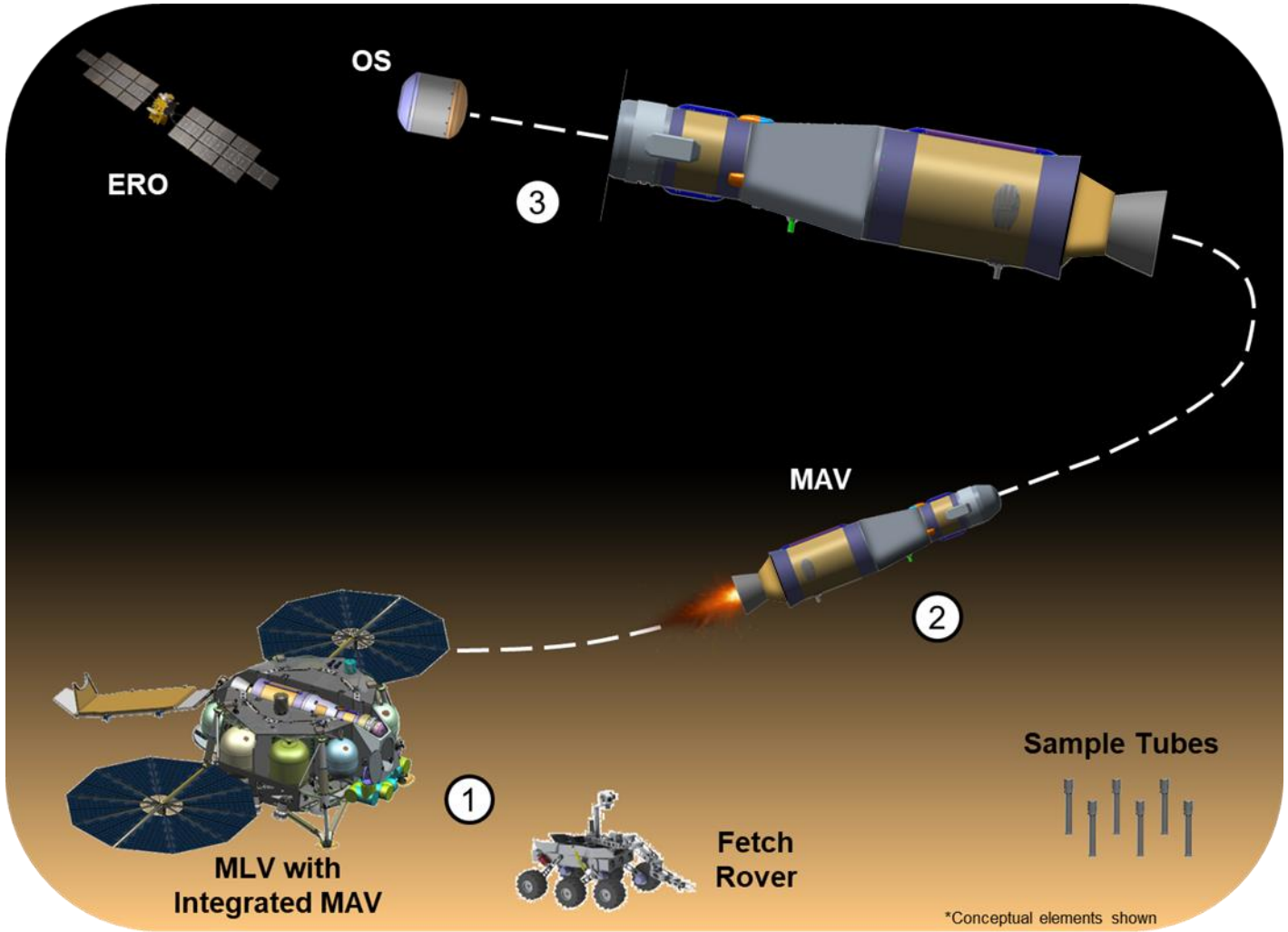
MAV Intro	MBSE Intro	MAV MBSE

*Images notional and subject to change

MAV Objectives

1. Receive sample tubes inside Orbiting Sample (OS) on Mars surface.
2. Launch OS to predefined Mars orbit.
3. Release OS in Mars orbit.

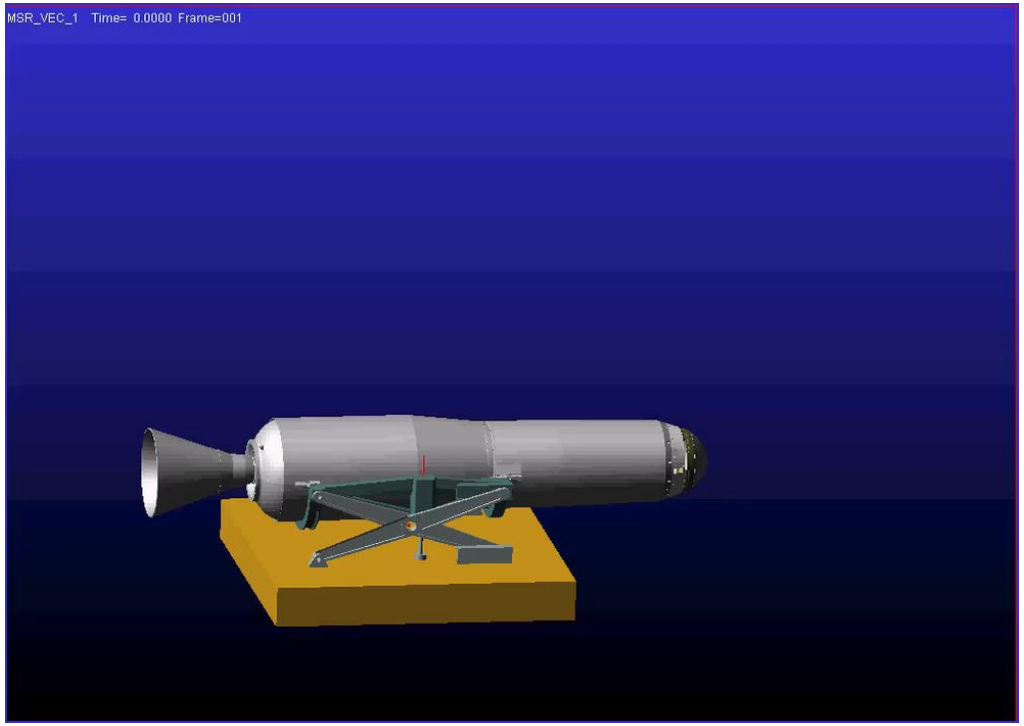


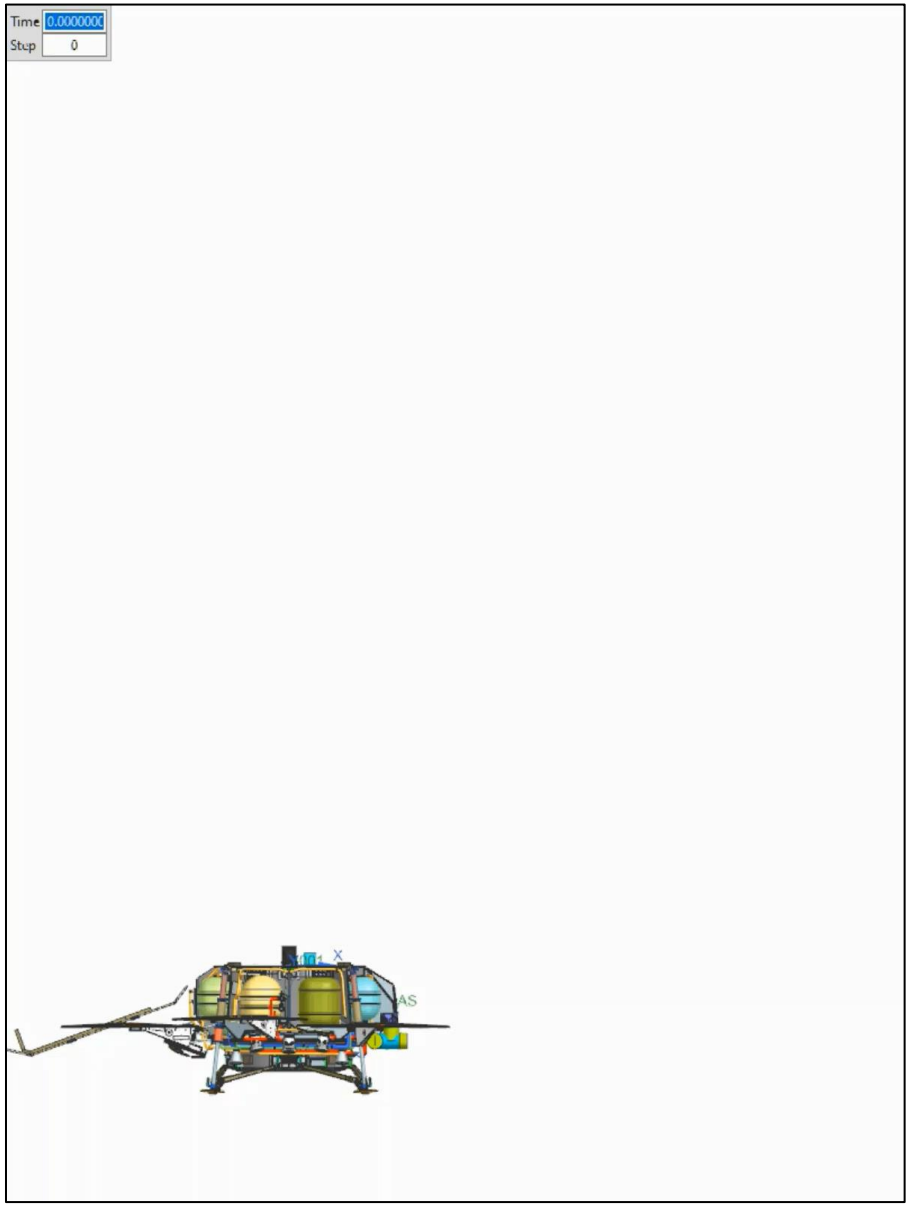


*Images notional and subject to change

MAV Launch Concept Videos - VECTOR

- Lander is only twice the mass of MAV so we don't want any points of contact at ignition.
  - Prevents MAV from dragging lander across surface.
- Also offers larger vertical clearance during liftoff.
  - Unknown exact landing terrain.





VECTOR - Vertical Egress, Controlled Tip-Off Rate

*Images notional and subject to change

What is Model-Based Systems Engineering?

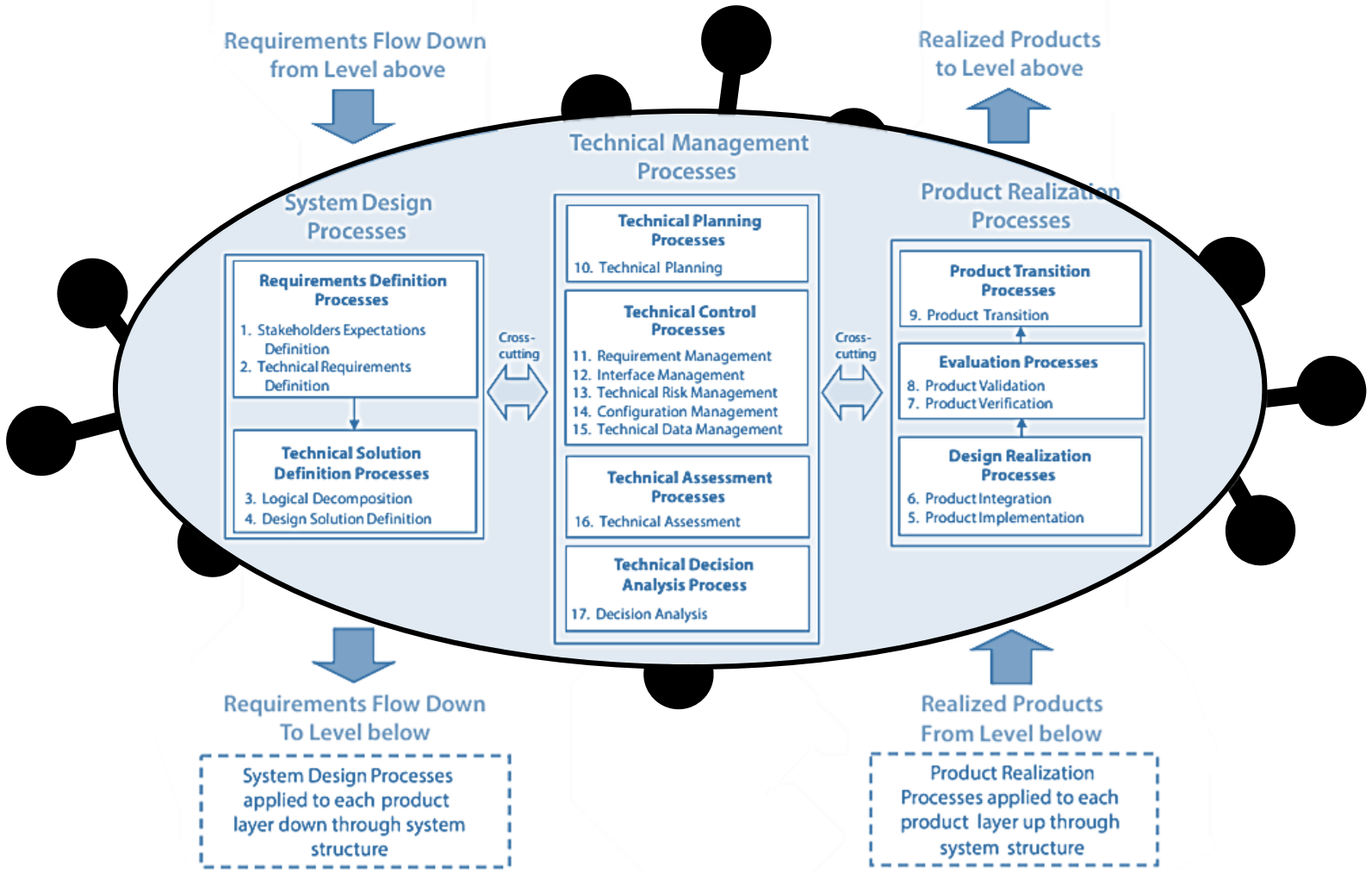
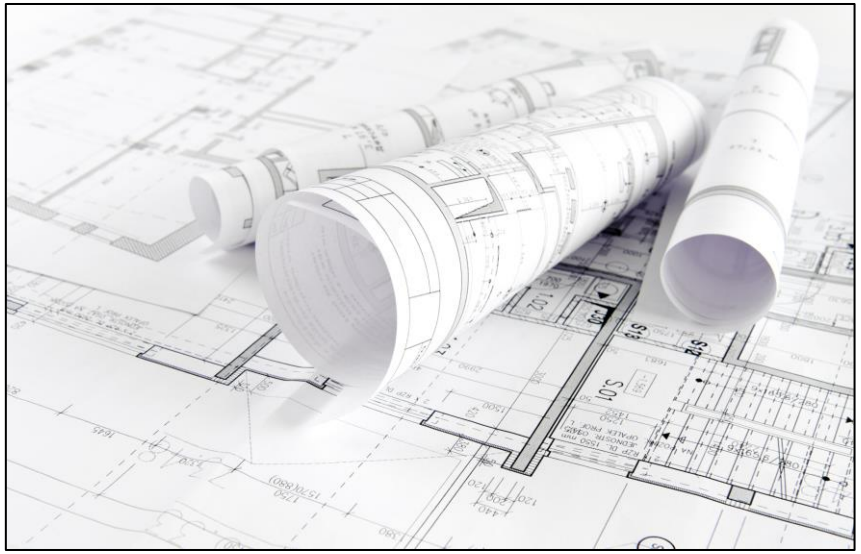
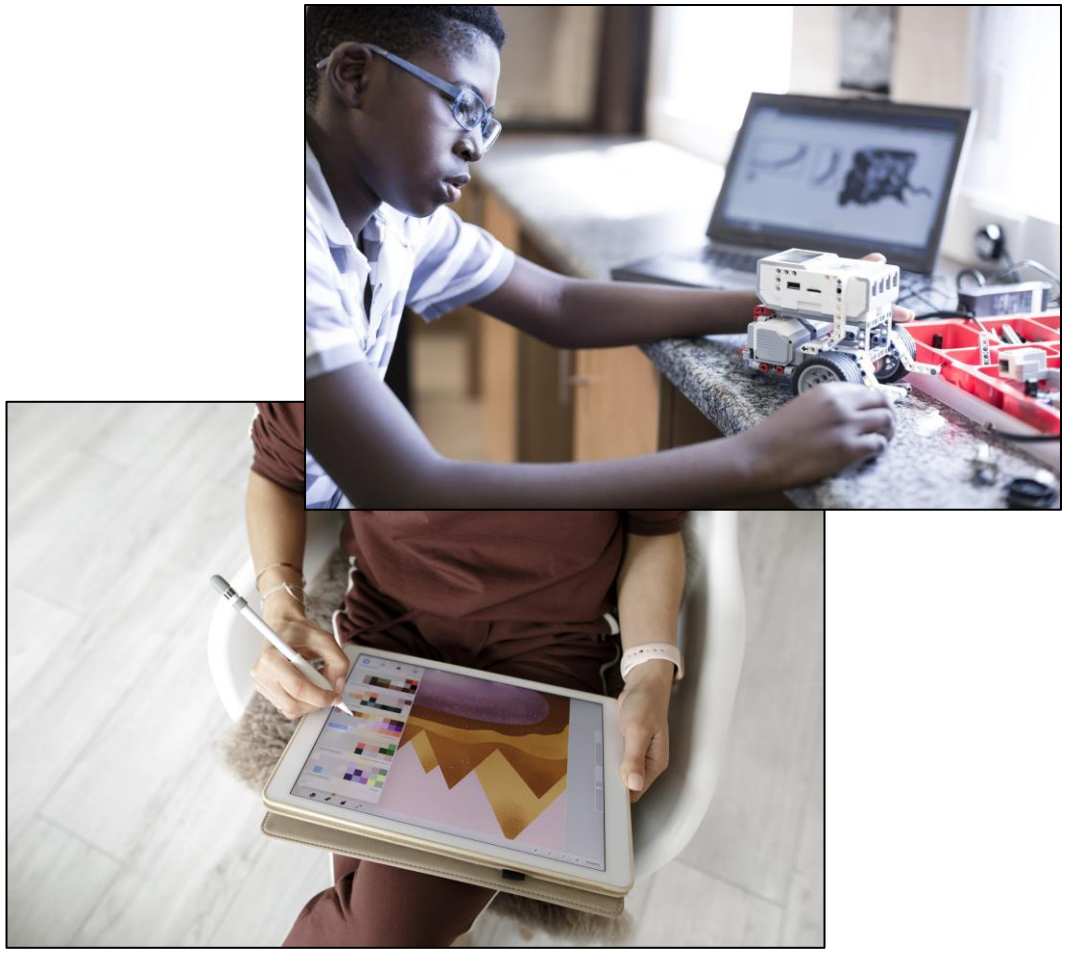


FIGURE 2.1-1 The Systems Engineering Engine (NPR 7123.1)

Understanding - What is MBSE?

- Model Based Systems Engineering (MBSE) is still systems engineering – you do the same processes and develop the same information.





Foundations - Why MBSE?

Increased precision of the system specification and design resulting in reduced downstream errors.

Improve traceability between system requirements, design, analysis, and verification information to enhance system design integrity.

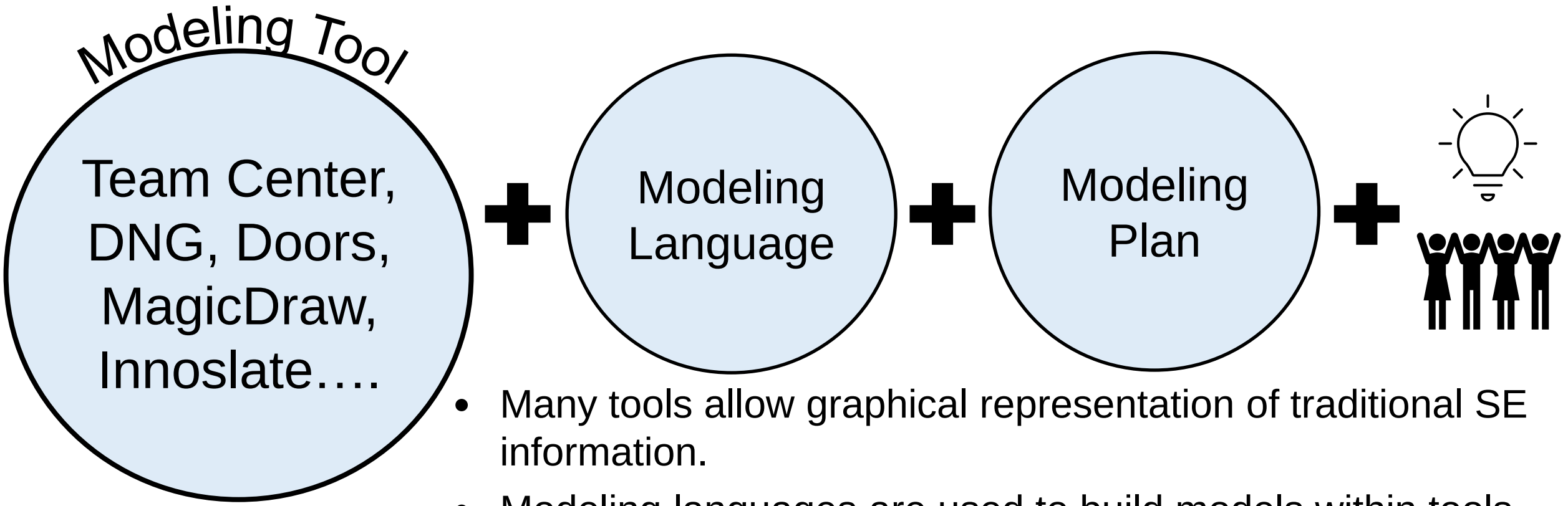
Improve the ability to maintain and evolve the system specification and design baseline throughout the system lifecycle.

Support reuse across projects.

Provide a shared understanding of the system to reduce miscommunication among the development team and stakeholders.

- *Architecting Spacecraft with SysML, A Model-Based Systems Engineering Approach*, by Sanford Friedenthal and Christopher Oster. Friedenthal & Oster, 2017.

What you need to do MBSE

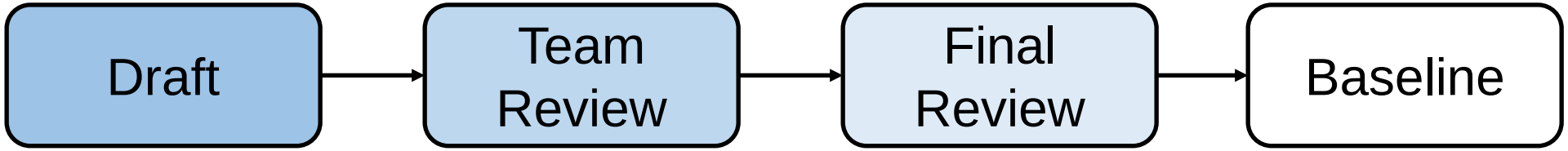


- Many tools allow graphical representation of traditional SE information.
- Modeling languages are used to build models within tools.
- Modeling languages offer a standardized specification and metamodel as a base for your system class structure (how to treat reqts vs behaviors vs structure).
- A modeling plan dictates what you will do in your SE process/effort. Can be the traditional plan or include the use of specific modeling frameworks and methods.

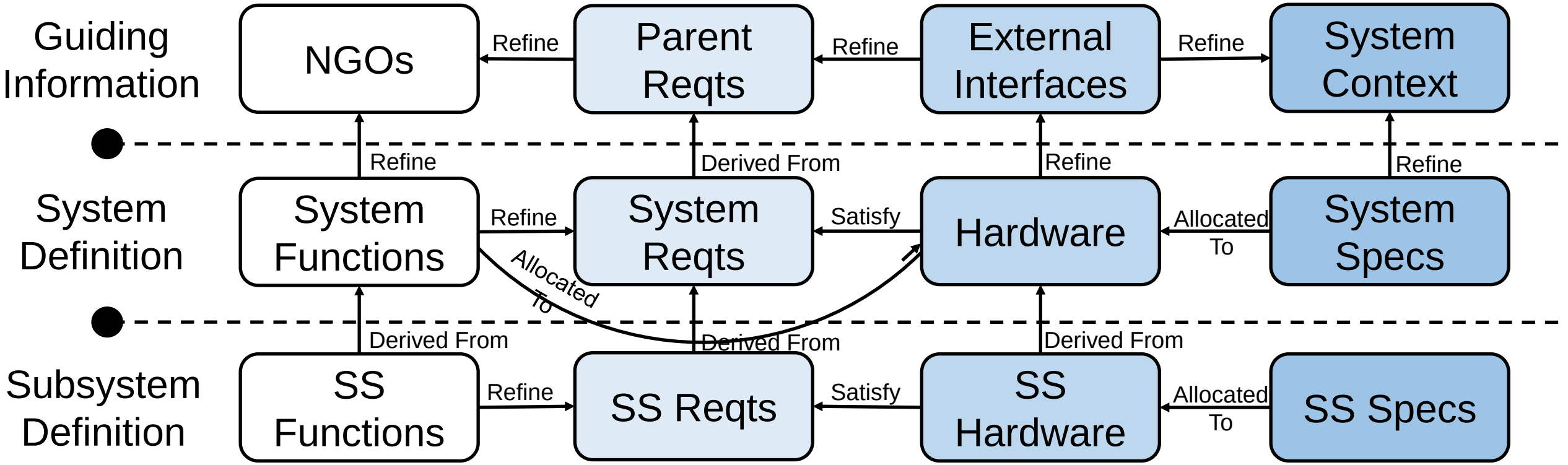
Branding Images from Vendor Sites

Model Focus Areas

- Models can serve as an area to manage & baseline SE artifacts.

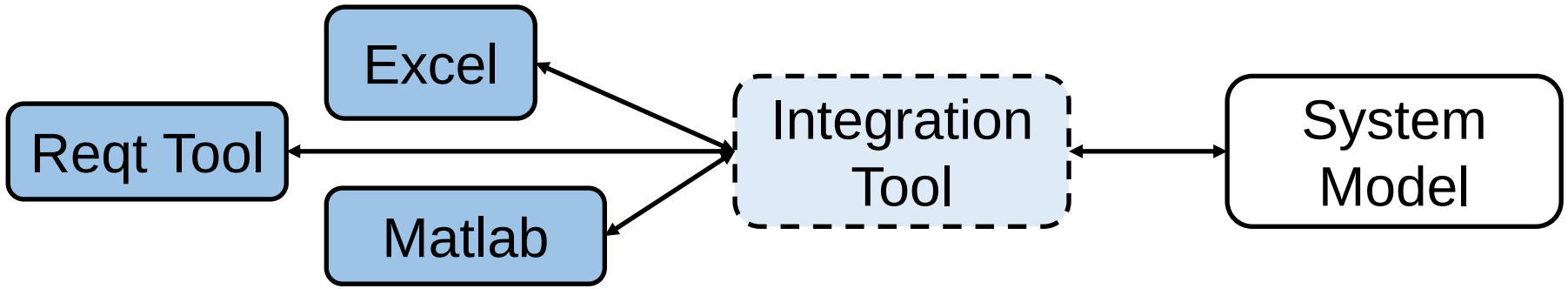


- Models enable mapping between layers of abstraction and across disciplines.



Integration, Languages, Methods, & Frameworks

- Many modeling tools can integrate with other tools to (usually via Open Services for Lifecycle Collaboration (OSLC) to assist with data import, exchange, & analysis.



- Modeling Languages:
  - Integration DEFinition (IDEF) : Method & Language
  - Object Process Methodogy (OPM) : Method & Language
  - Systems Modeling Language (SysML) : Language
  - Unified Modeling Language (UML) : Language
- Method: Set of logical processes and practices to model a system. (What & Why)
- Framework: Structured approach to modeling the system. (Box Check)

Methods & Frameworks

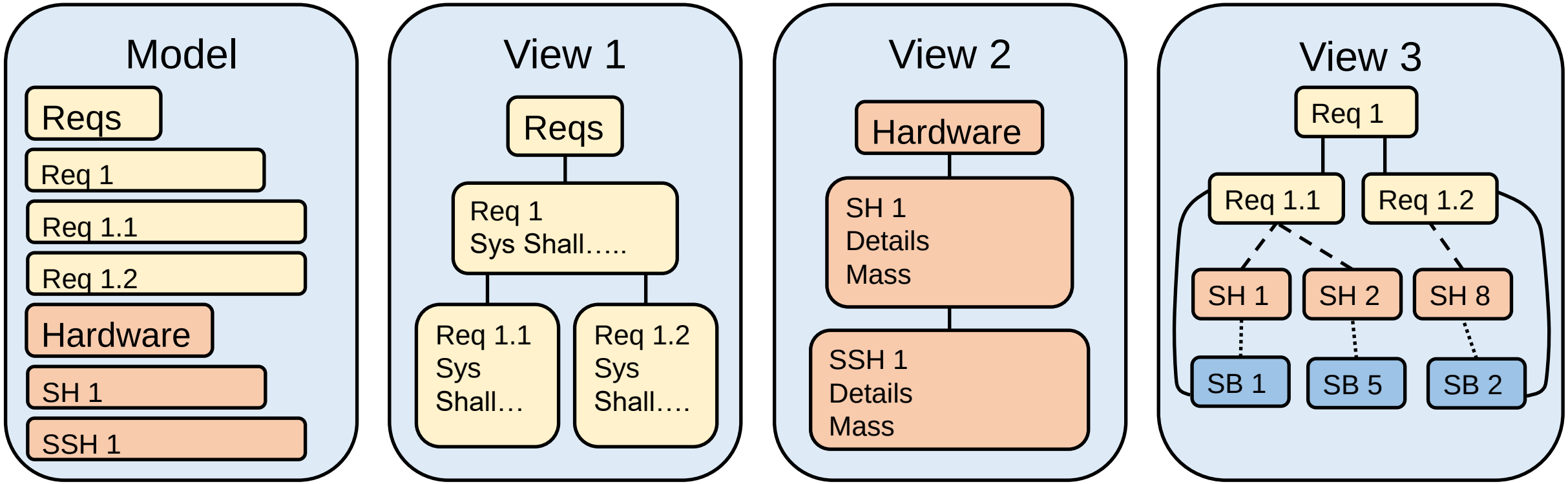
- Modeling Methodologies (courtesy of omgwiki)
  - Object-Oriented Systems Engineering Method (OOSEM)
  - IBM Rational Telelogic Harmony - SE
  - IBM Rational Unified Process for Systems Engineering (RUP-SE)
  - Vitech Model-Based Systems engineering (MBSE) Methodology|Vitech
  - JPL State Analysis (SA) Methodology
  - Weilkiens Systems Modeling Process (SYSMOD)
  - Pattern-Based Systems Engineering (PBSE)
- Modeling Frameworks
  - Ministry of Defence Architecture Framework (MODAF)
  - Unified Architecture Framework (UAF)
  - MagicGrid

What a Framework Could Look Like

System Level	Requirements	Behavior	Structure
	A1. Stakeholder Needs Diagram	B1. Functional Decomposition Diagram	C1. External Interface Diagram
	A2. System Context Diagram	B2. Concept of Operations Diagram	C2. Internal System Interfaces Diagram
	A3. Requirements Context Diagram	B3. Operational Concept Diagram	C3. System Architecture Diagram
	A4. Requirements Diagram	B4. SW Sequence Diagram	C4. Data Architecture Diagram

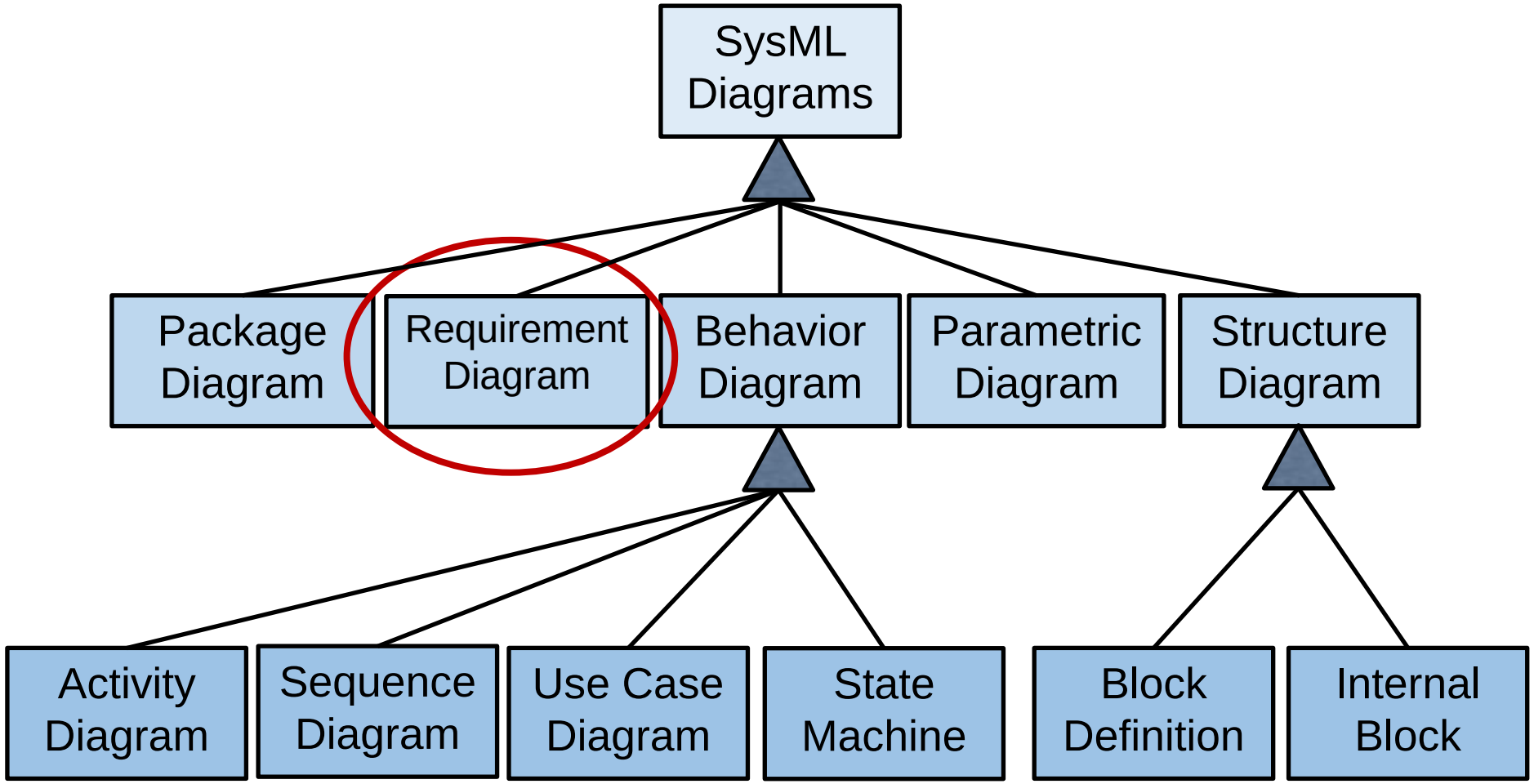
More About Modeling Tools

- Allow the creation of views and viewpoints tailored to specific audience to aid in communication of system information.

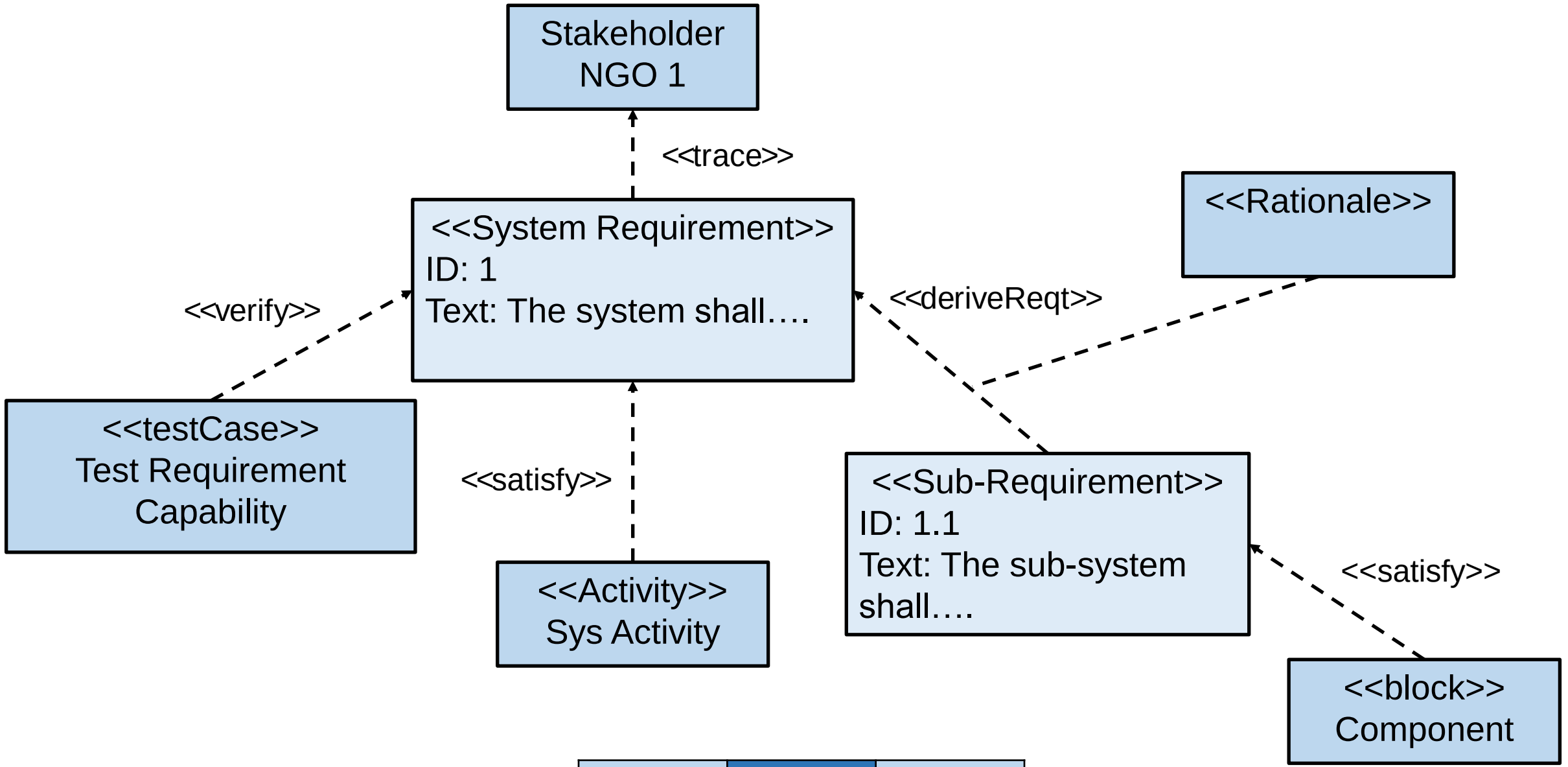


- Many modeling tools include report/publishing capabilities to export documents, spreadsheets, PowerPoints, and web-resources.
- Web publishing and collaboration is a very useful capability.

A Look into SysML - Diagrams

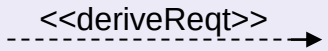
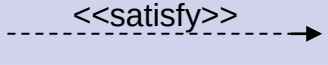
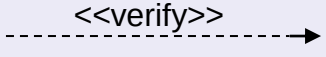
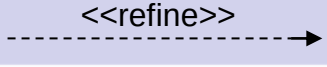
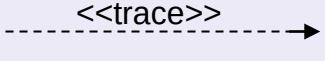
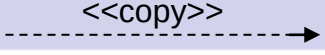


A Look into SysML – Requirements Diagram



A Look into SysML – Reqt Relationships

Requirement Relationships

Diagram Element	Notation	Description
Containment Path		Represents how requirements are contained in specifications (packages) and also used in package diagrams to define the structure of folders in the containment window
Derivation Path		Relation between a source requirement and a derived requirement based on analysis of the source requirement; most commonly used relation for parent/child trace
Satisfaction Path		Assert that a model element corresponding to design or implementation satisfies a requirement
Verification Path		Use between a requirement and a test case or other named element to indicate how to verify that the requirement is satisfied
Refinement Path		Use to reduce ambiguity in a requirement by relating it to another model element that clarifies the requirement
Trace Path		General purpose relationship used to relate a requirement to any other model element, typically a reference document
Copy Path		Relates a copy of a requirement to the original requirement to support reuse of requirements.

How do we Make MBSE Work on MAV?

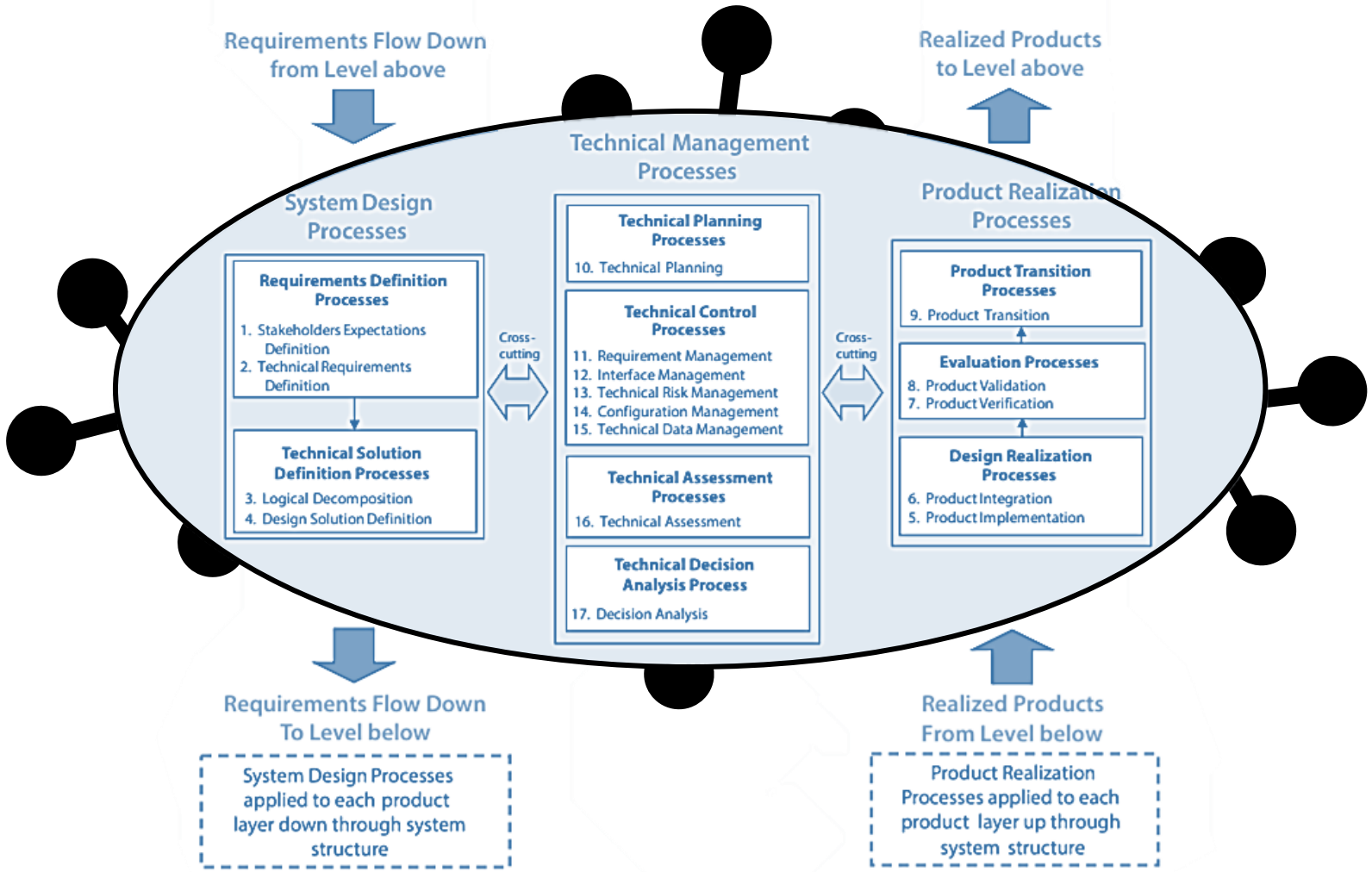


FIGURE 2.1-1 The Systems Engineering Engine (NPR 7123.1)

MAV Intro	MBSE Intro	MAV MBSE

Getting Started with Lessons Learned

Lessons learned from EUROPA mission studies:

‘Automated Web-Based Model Reports are Critical’

- MAV uses MagicDraw Teamwork Cloud with Cameo Collaborator Publisher to publish model views to a collaborative web portal.

‘Keep the Focus on Engineering Products’

- To ensure systems engineering modeling efforts remained focused on products, a product-driven modeling approach was pursued.

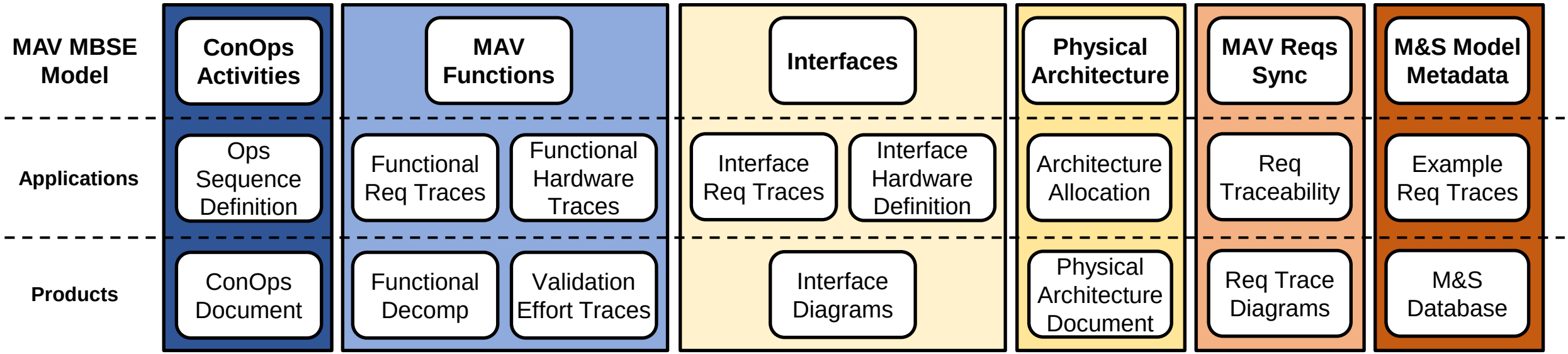
‘Early Efforts Draw on a Limited Pool of Talent’

- Sometimes it’s more efficient to hire outside expertise than train internal talent. A MBSE subject matter expert was hired to help implement model-based practice within the MAV SE team.

‘Everyone Needs Training, but to Different Levels’

- MAV team members were trained in modeling as-needed for product development.

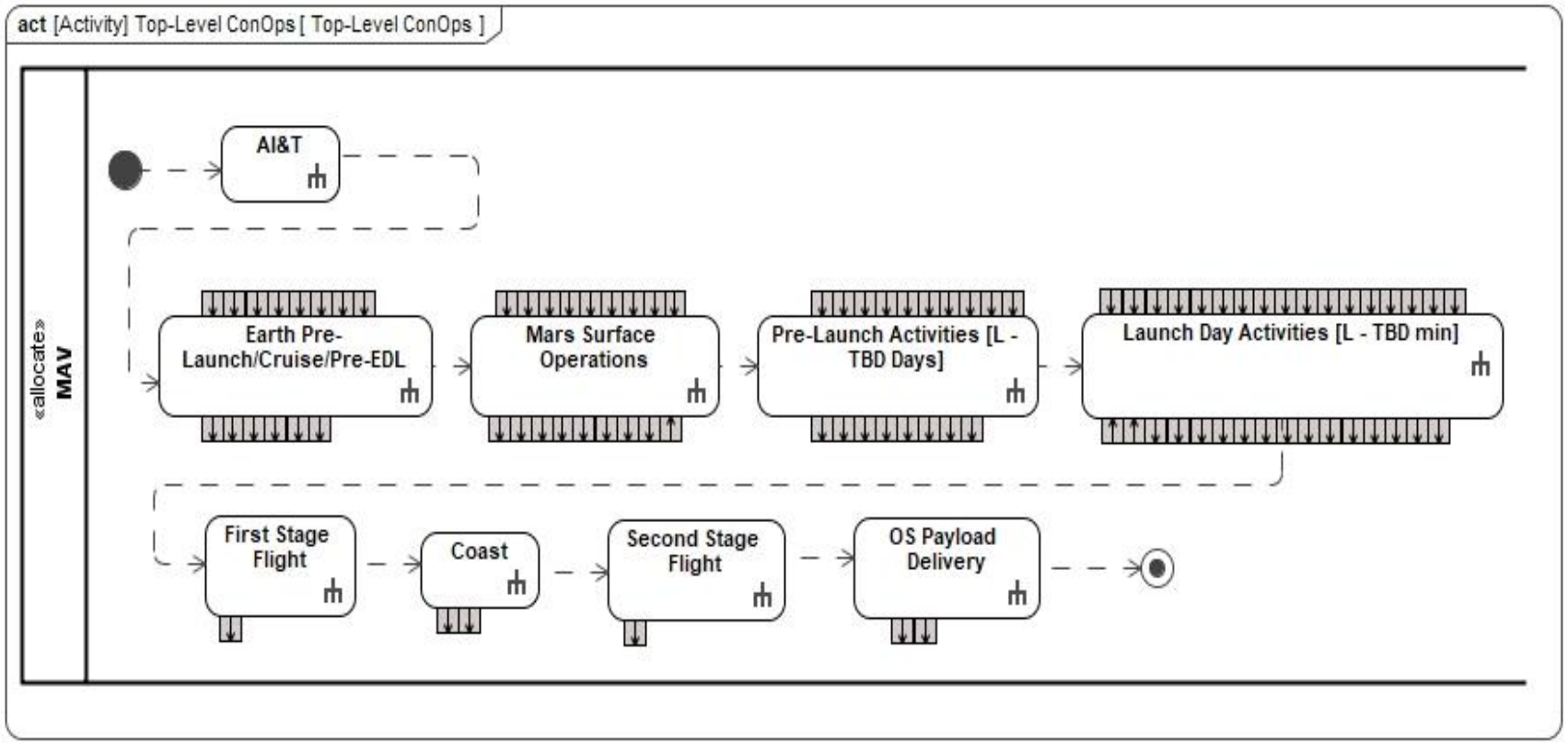
MAV MBSE Applications & Products



Ops – Operations
Req(s) – Requirements
Decomp – Decomposition

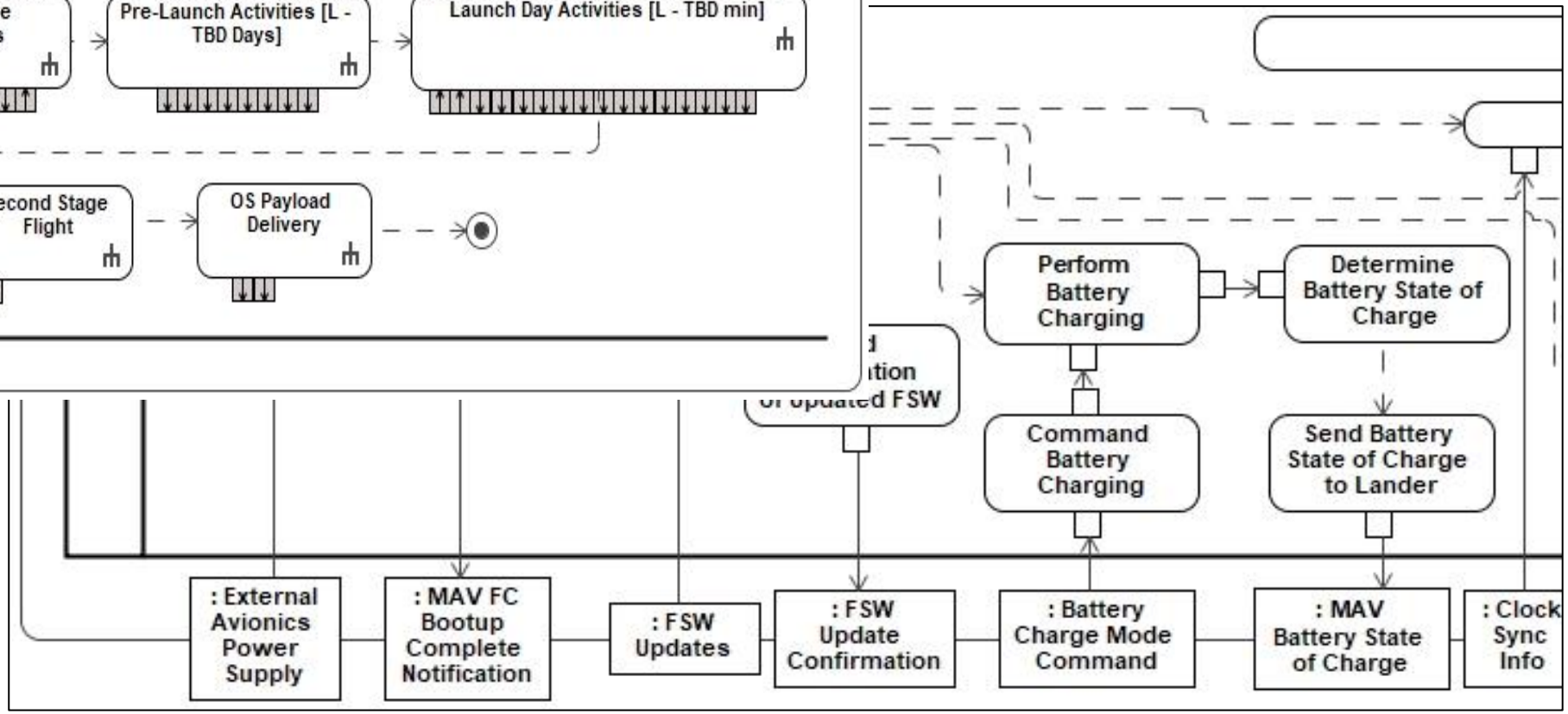
MAV Intro | MBSE Intro | MAV MBSE

Concept of Operations (ConOps) Diagrams



Based on FFBD's, ConOps diagrams defined to address interface definition between MAV and MLP.

Captures input/output flow, commanding, and activity sequencing.



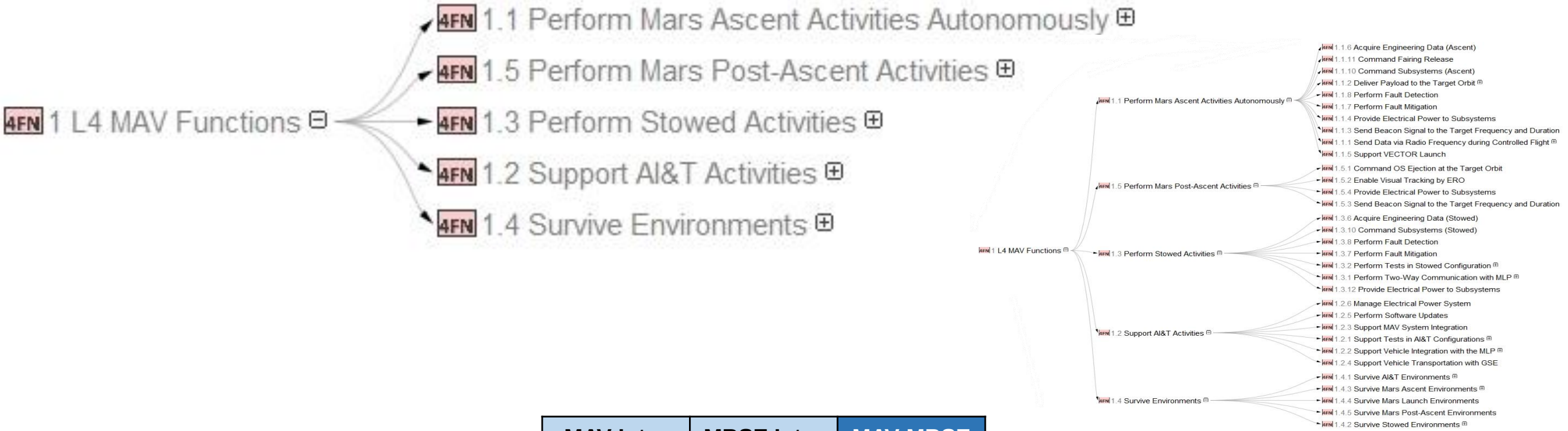
FFBD – Functional Flow Block Diagram

MAV Intro | MBSE Intro | MAV MBSE

Functional Decomposition

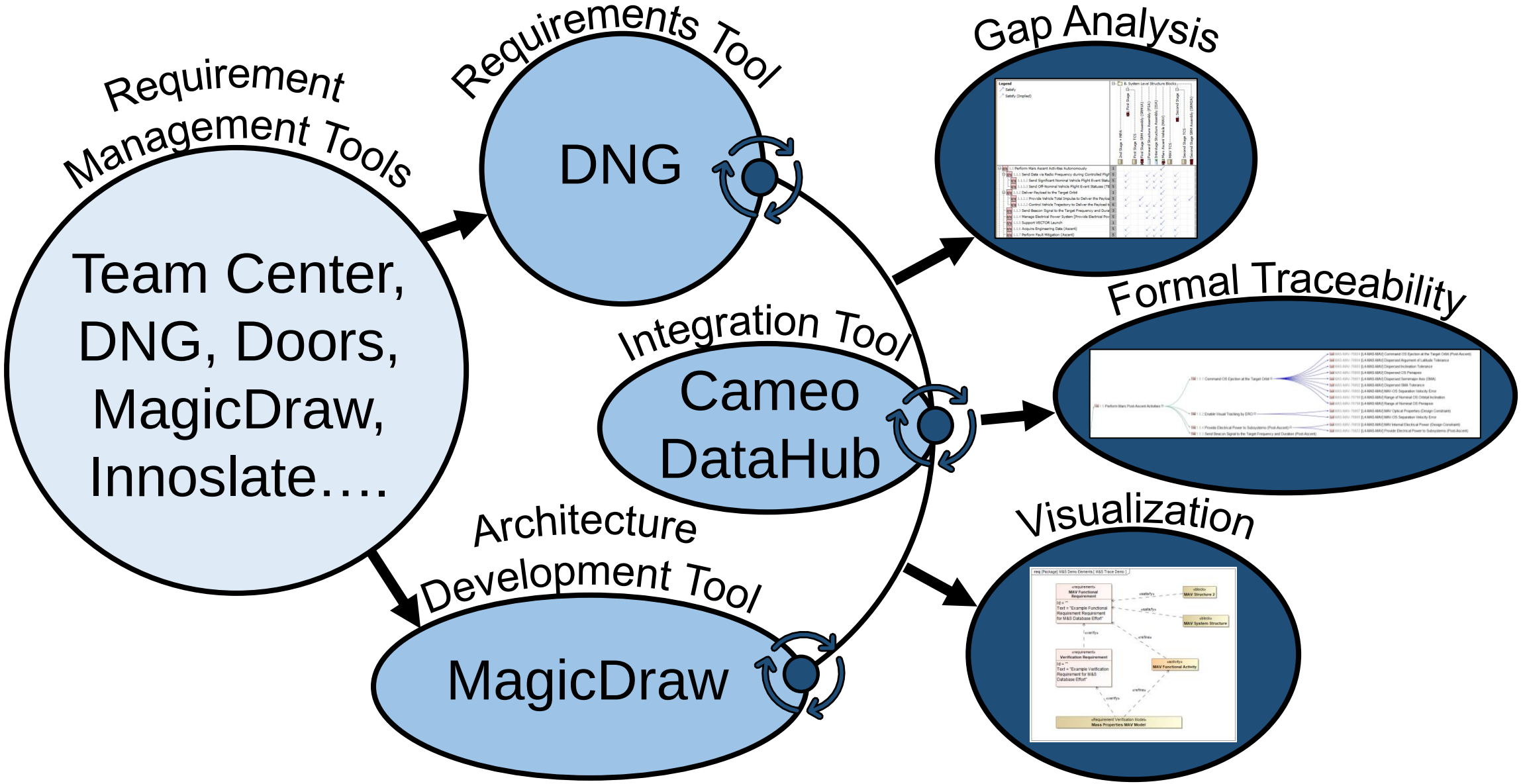
To facilitate functional requirement development, a functional decomposition was developed in the model.

- Focus on top-down functional decomposition with reference to ConOps diagrams.
- At level 4, vehicle level, kept as design independent as possible – hinging on high-level concept decisions such as the two-stage-to-orbit design.



MAV Intro	MBSE Intro	MAV MBSE

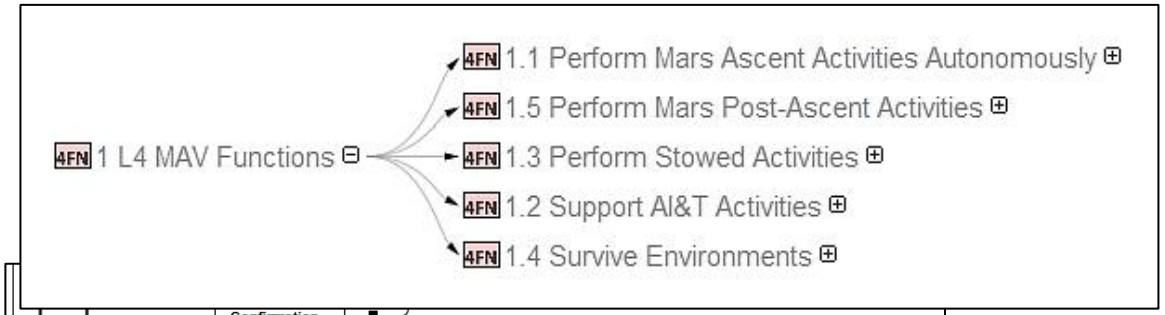
Requirements Traceability

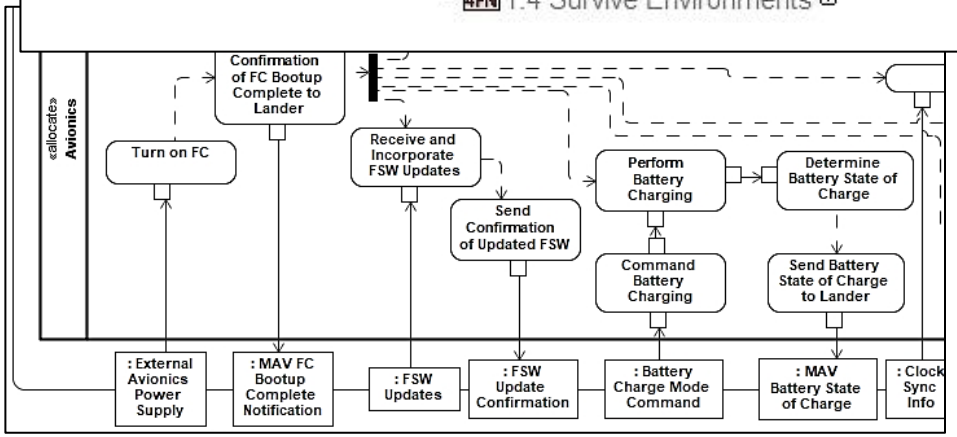


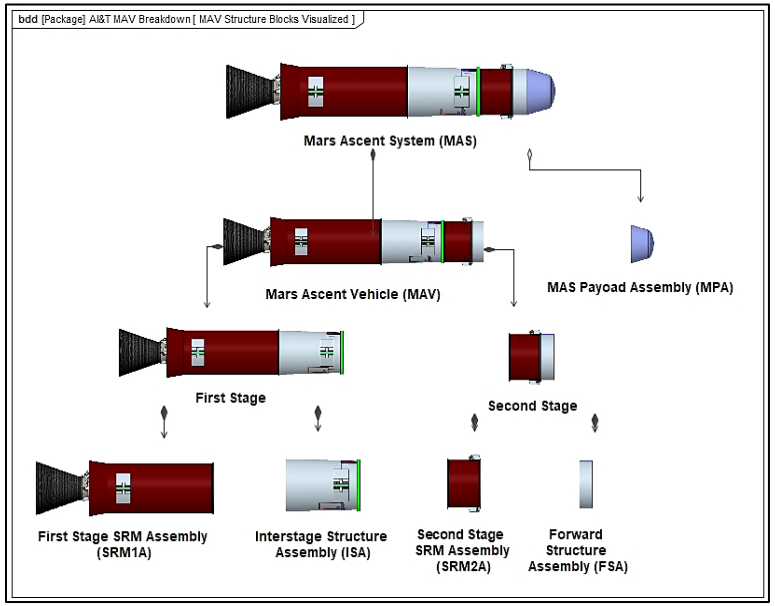
MAV Intro	MBSE Intro	MAV MBSE

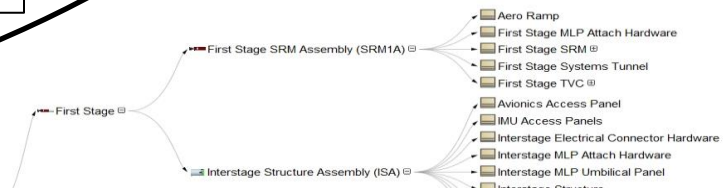
Branding Images from Vendor Sites

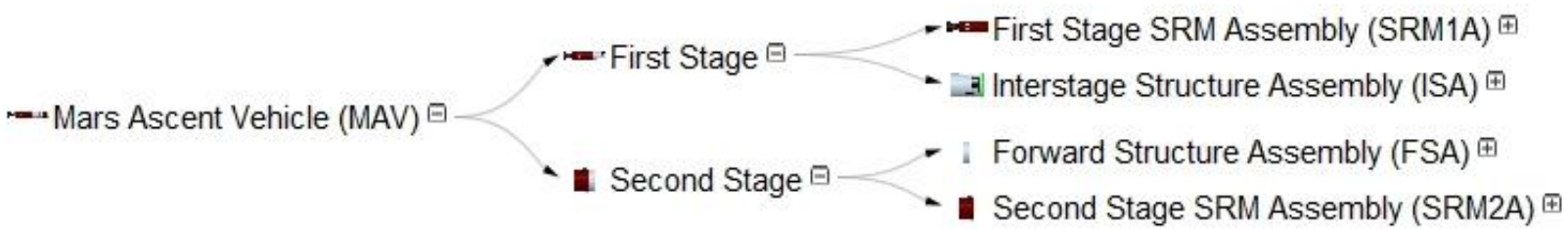
Physical Architecture Definition











MAV Physical Architecture Map Document

MAV Intro	MBSE Intro	MAV MBSE

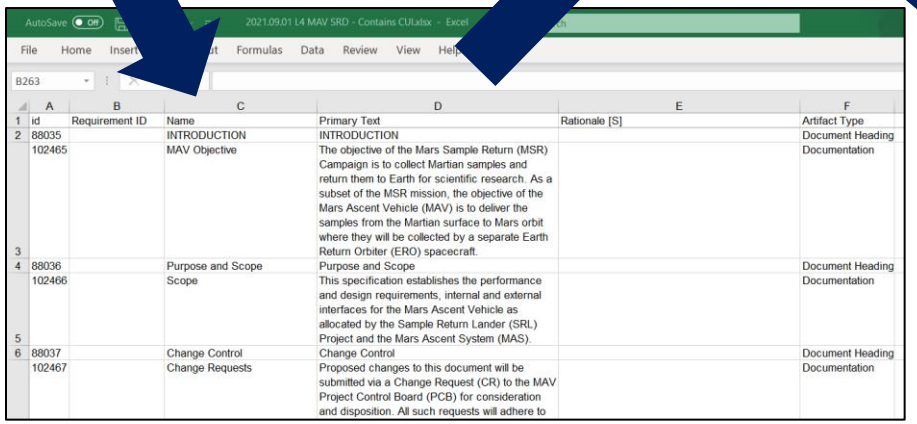
Interface Definition

National Aeronautics and Space Administration
Jet Propulsion Laboratory / Marshall Space Flight Center
Mars Sample Return / Mars Ascent Vehicle

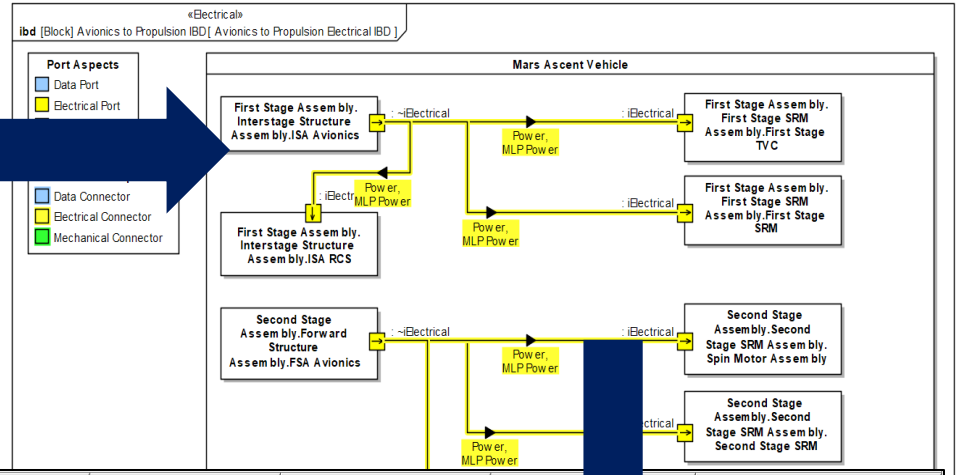
Traditional | Model-Assisted

MLP	(MLP to MPA) Not within MAV purview	(MLP to Avionics) **Electrical Interface** MLP to Avionics **Functional Interface** MLP to provide power to Avionics MLP to provide avionics on/off signal to Avionics MLP to provide comm & data to Avionics MLP to provide pyro inhibits signal to Avionics MLP to provide pyro switch command to Avionics	(MLP to Propulsion) **Mechanical Interface** MLP to SRM1 attach point MLP to SRM1 keep MLP to SRM2 keep MLP to RCS keep
(MPA to MLP) Not within MAV purview	**MPA**	(MPA to Avionics) **Mechanical Interface** MPA to Avionics keep out zones **Electrical Interface** MPA to Avionics **Functional Interface** MPA to provide fairing status to Avionics	(MPA to Propulsion) **Mechanical Interface** MPA to SRM2 keep out zones
(Avionics to MLP) **Electrical Interface** Avionics to MLP **Functional Interface** Avionics to provide comm & data to MLP ~Avionics to provide analog battery charge status to MLP ~Avionics to provide analog thermal data to MLP ~Avionics to provide health and status to MLP ~Avionics to provide analog pyro status to MLP	(Avionics to MPA) **Electrical Interface** Avionics to MPA **Functional Interface** Avionics to send OS release pyro command to MPA	**Avionics**	(Avionics to Propulsion) **Electrical Interface**
(Propulsion to MLP) **Mechanical Interface** SRM1 to MLP attach point	(Propulsion to MPA) **Mechanical Interface** SRM2 to MPA keep out zones **Functional Interface** 2 to route fairing release pyro command to	(Propulsion to Avionics) **Electrical Interface** SRM1 to Avionics SRM1 TVC to Avionics SRM2 to Avionics **Functional Interface** SRM1 thermal sensors to provide thermal data to Avionics SRM1 pressure transducers to provide pressure data to Avionics SRM1 TVC to provide health and status to Avion SRM1 TVC to provide engineering data to Avion SRM2 thermal sensors to provide thermal dat	

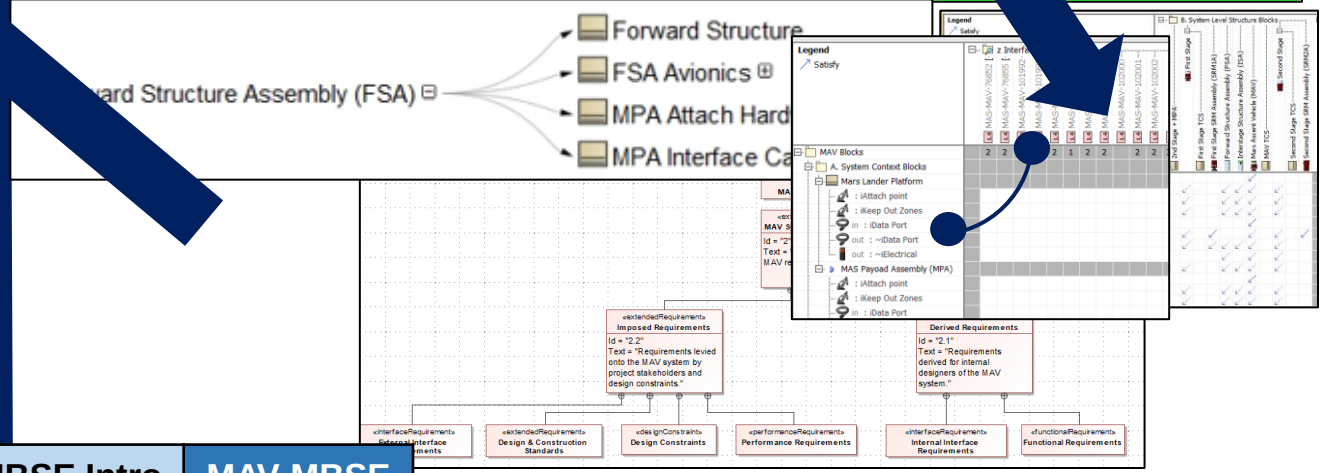
MAV Requirements Documents



	A	B	C	D	E	F
1	id	Requirement ID	Name	Primary Text	Rationale [S]	Artifact Type
2	88035		INTRODUCTION	INTRODUCTION		Document Heading
	102465		MAV Objective	The objective of the Mars Sample Return (MSR) Campaign is to collect Martian samples and return them to Earth for scientific research. As a subset of the MSR mission, the objective of the Mars Ascent Vehicle (MAV) is to deliver the samples from the Martian surface to Mars orbit where they will be collected by a separate Earth Return Orbiter (ERO) spacecraft.		Documentation
3						
4	88036		Purpose and Scope	Purpose and Scope		Document Heading
	102466		Scope	This specification establishes the performance and design requirements, internal and external interfaces for the Mars Ascent Vehicle as allocated by the Sample Return Lander (SRL) Project and the Mars Ascent System (MAS).		Documentation
5						
6	88037		Change Control	Change Control		Document Heading
	102467		Change Requests	Proposed changes to this document will be submitted via a Change Request (CR) to the MAV Project Control Board (PCB) for consideration and disposition. All such requests will adhere to		Documentation



Part A	Port A	Port A Features	Item Flow	Port	Part B
First Stage TVC	in : iElectrical	F in : Power	MLP Power	in : iElectrical	SRM 1 TVC Therm...
First Stage TVC	in : iElectrical	F in : Power	MLP Power	in : iElectrical	TVC Controller Hea...
First Stage TVC	in : iData Port	F in : Data	Command sig	in : iData Port	TVC Controller : TV...
First Stage TVC	in : iElectrical	F in : Power	Power	in : iElectrical	TVC Controller : TV...
First Stage TVC	in : iData Port	F in : Data	Pyro comman	in : iData Port	TVC Thermal Batt...



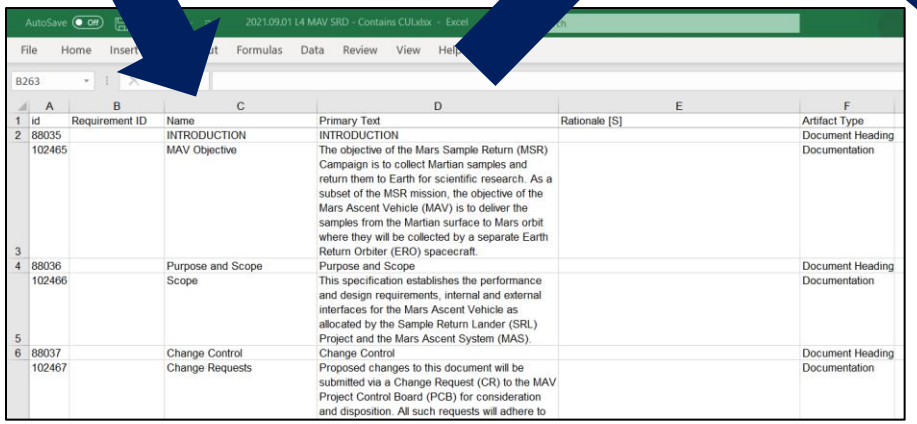
MAV Intro | **MBSE Intro** | **MAV MBSE**

Interface Definition Cont.

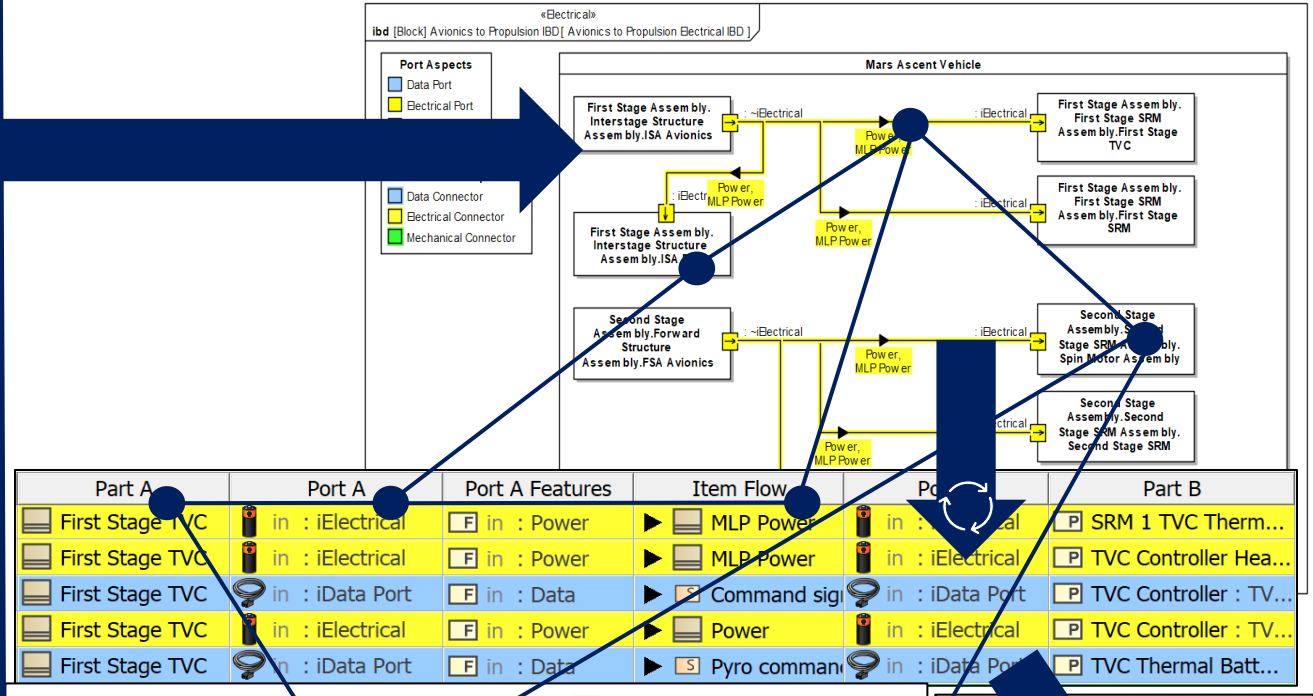
Traditional | Model-Assisted

MLP	(MLP to MPA) Not within MAV purview	(MLP to Avionics) **Electrical Interface** MLP to Avionics **Functional Interface** MLP to provide power to Avionics MLP to provide avionics on/off signal to Avionics MLP to provide comm & data to Avionics MLP to provide pyro inhibits signal to Avionics MLP to provide pyro switch command to Avionics	(MLP to Propulsion) **Mechanical Interface** MLP to SRM1 attach point MLP to SRM1 keep MLP to SRM2 keep MLP to RCS keep
(MPA to MLP) Not within MAV purview	**MPA**	(MPA to Avionics) **Mechanical Interface** MPA to Avionics keep out zones **Electrical Interface** MPA to Avionics **Functional Interface** MPA to provide fairing status to Avionics	(MPA to Propulsion) **Mechanical Interface** MPA to SRM2 keep out zones
(Avionics to MLP) **Electrical Interface** Avionics to MLP **Functional Interface** Avionics to provide comm & data to MLP -Avionics to provide analog battery charge status to MLP -Avionics to provide analog thermal data to MLP -Avionics to provide health and status to MLP -Avionics to provide analog pyro status to MLP	(Avionics to MPA) **Electrical Interface** Avionics to MPA **Functional Interface** Avionics to send OS release pyro command to MPA	**Avionics**	(Avionics to Propulsion) **Electrical Interface**
(Propulsion to MLP) **Mechanical Interface** SRM1 to MLP attach point	(Propulsion to MPA) **Mechanical Interface** SRM2 to MPA keep out zones **Functional Interface** 2 to route fairing release pyro command to	(Propulsion to Avionics) **Electrical Interface** SRM1 to Avionics SRM1 TVC to Avionics SRM2 to Avionics **Functional Interface** SRM1 thermal sensors to provide thermal data to Avionics SRM1 pressure transducers to provide pressure data to Avionics SRM1 TVC to provide health and status to Avion SRM1 TVC to provide engineering data to Avion SRM2 thermal sensors to provide thermal dat	

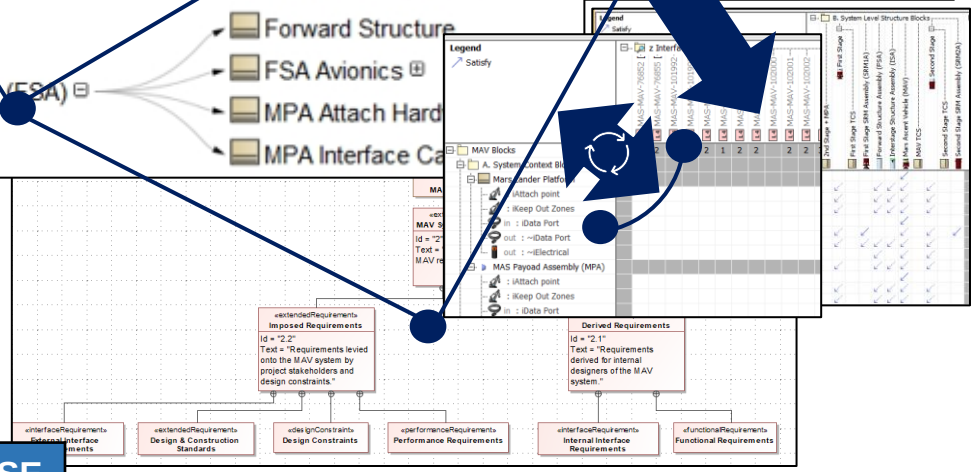
MAV Requirements Documents



	A	B	C	D	E	F
1	id	Requirement ID	Name	Primary Text	Rationale [S]	Artifact Type
2	88035		INTRODUCTION	INTRODUCTION		Document Heading
	102465		MAV Objective	The objective of the Mars Sample Return (MSR) Campaign is to collect Martian samples and return them to Earth for scientific research. As a subset of the MSR mission, the objective of the Mars Ascent Vehicle (MAV) is to deliver the samples from the Martian surface to Mars orbit where they will be collected by a separate Earth Return Orbiter (ERO) spacecraft.		Documentation
3						
4	88036		Purpose and Scope	Purpose and Scope		Document Heading
	102466		Scope	This specification establishes the performance and design requirements, internal and external interfaces for the Mars Ascent Vehicle as allocated by the Sample Return Lander (SRL) Project and the Mars Ascent System (MAS).		Documentation
5						
6	88037		Change Control	Change Control		Document Heading
	102467		Change Requests	Proposed changes to this document will be submitted via a Change Request (CR) to the MAV Project Control Board (PCB) for consideration and disposition. All such requests will adhere to		Documentation

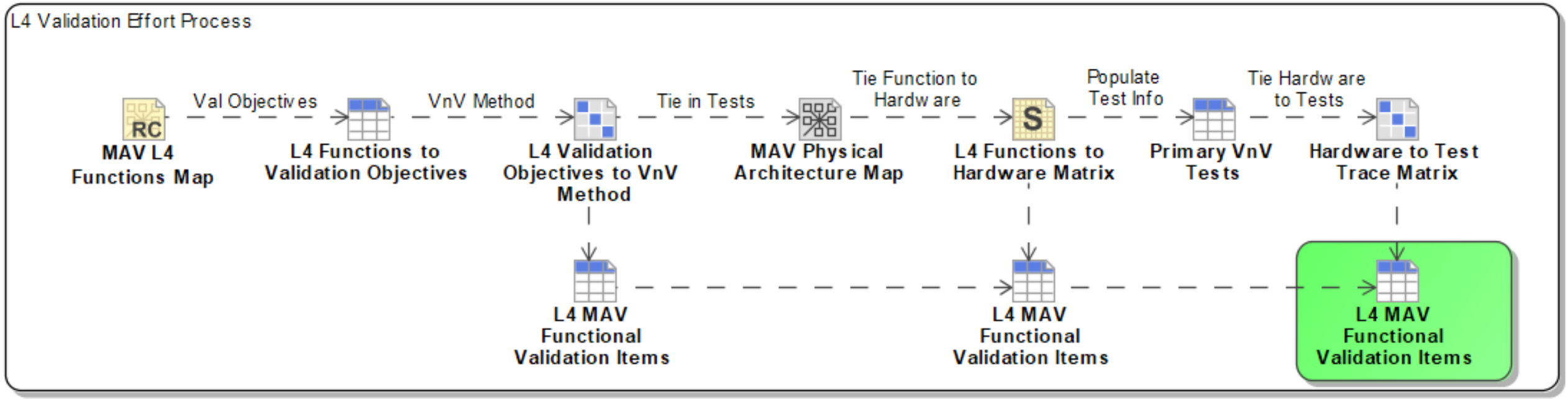


Part A	Port A	Port A Features	Item Flow	Port	Part B
First Stage TVC	in : iElectrical	F in : Power	MLP Power	in : iElectrical	P SRM 1 TVC Therm...
First Stage TVC	in : iElectrical	F in : Power	MLP Power	in : iElectrical	P TVC Controller Hea...
First Stage TVC	in : iData Port	F in : Data	Command sig	in : iData Port	P TVC Controller : TV...
First Stage TVC	in : iElectrical	F in : Power	Power	in : iElectrical	P TVC Controller : TV...
First Stage TVC	in : iData Port	F in : Data	Pyro comman	in : iData Port	P TVC Thermal Batt...



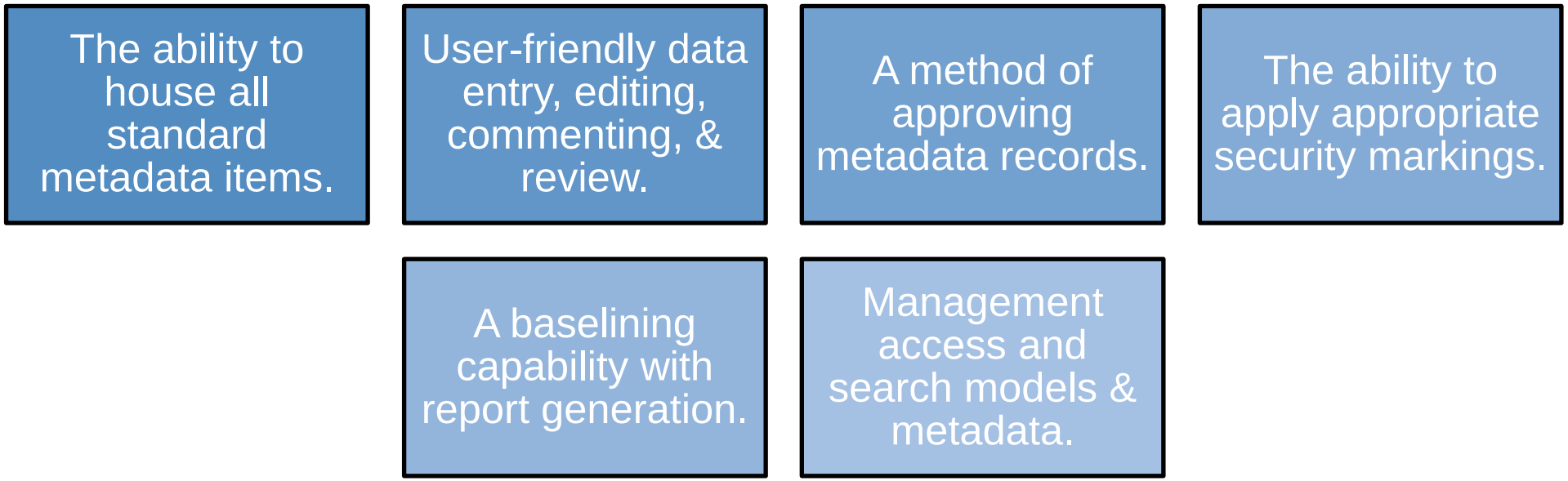
MAV Intro | **MBSE Intro** | **MAV MBSE**

Validation Item Development



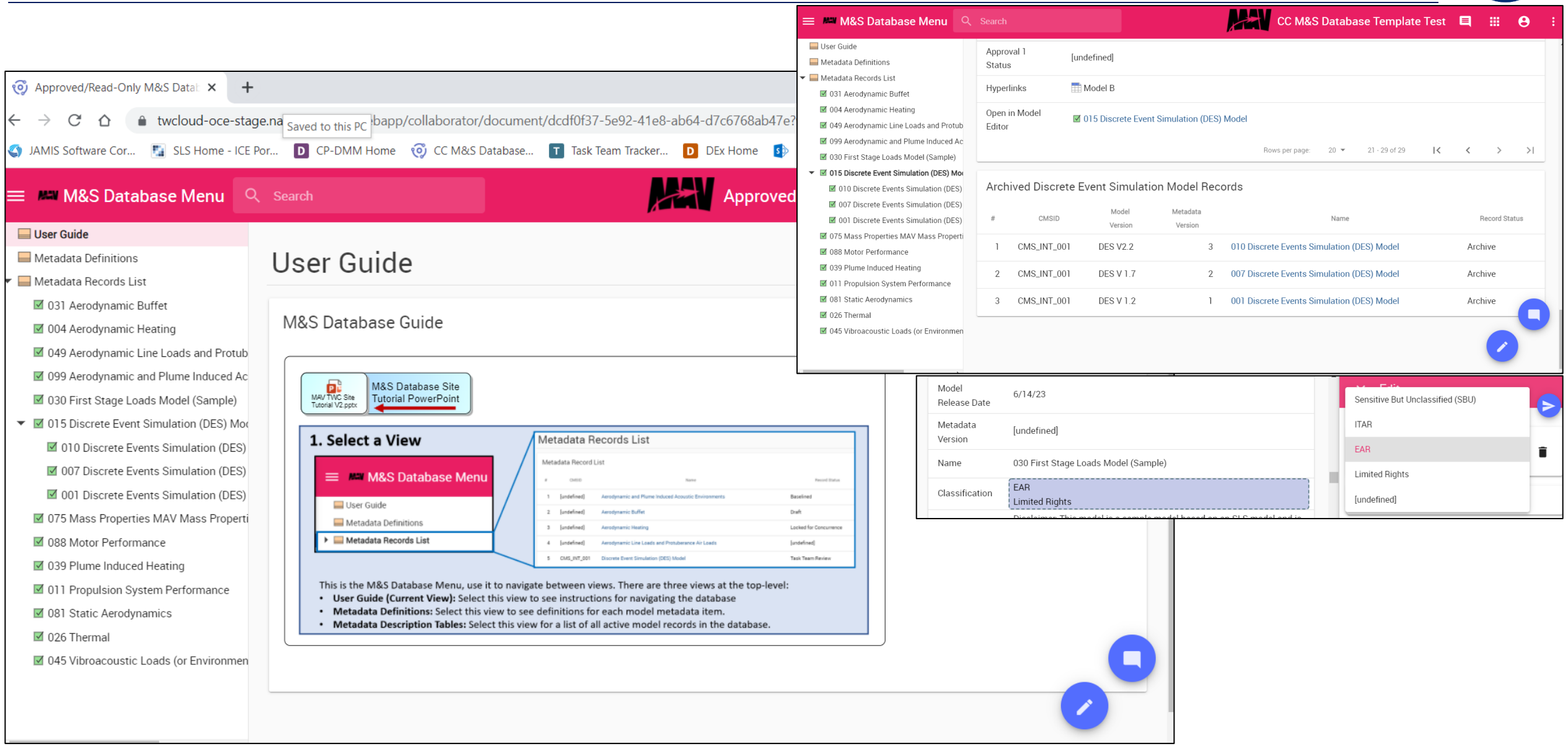
Models & Simulations (M&S) Database Concept

MagicDraw evaluated as a potential cost-free alternative tool option for M&S metadata management against legacy tool capabilities, offering potential cost savings.



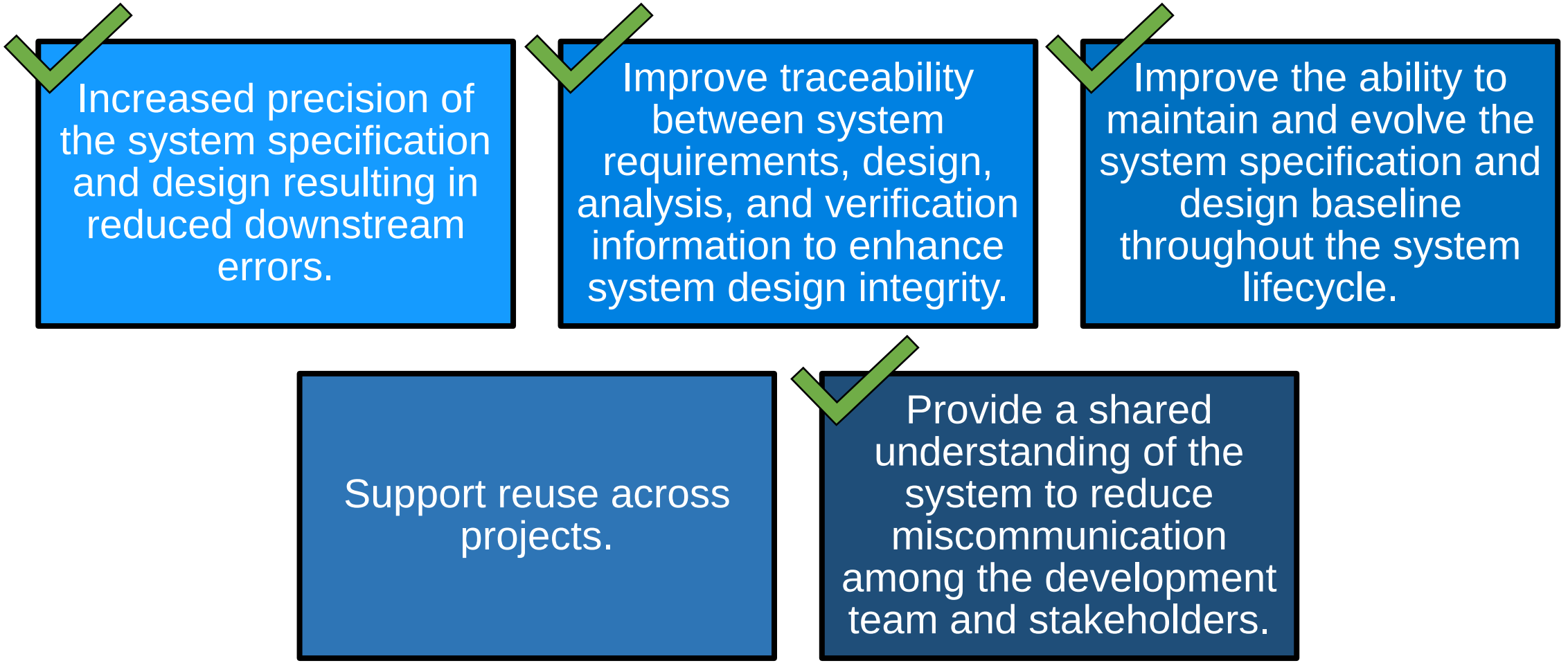
- A M&S database concept in MagicDraw was developed using Cameo Collaborator Publisher.
- Before the MAV SRR, the MagicDraw M&S database proof of concept successfully met base capability expectations. Implementation of the tool is being tested with available metadata record information, in preparation for the next milestone review.

M&S Database Concept Cont.



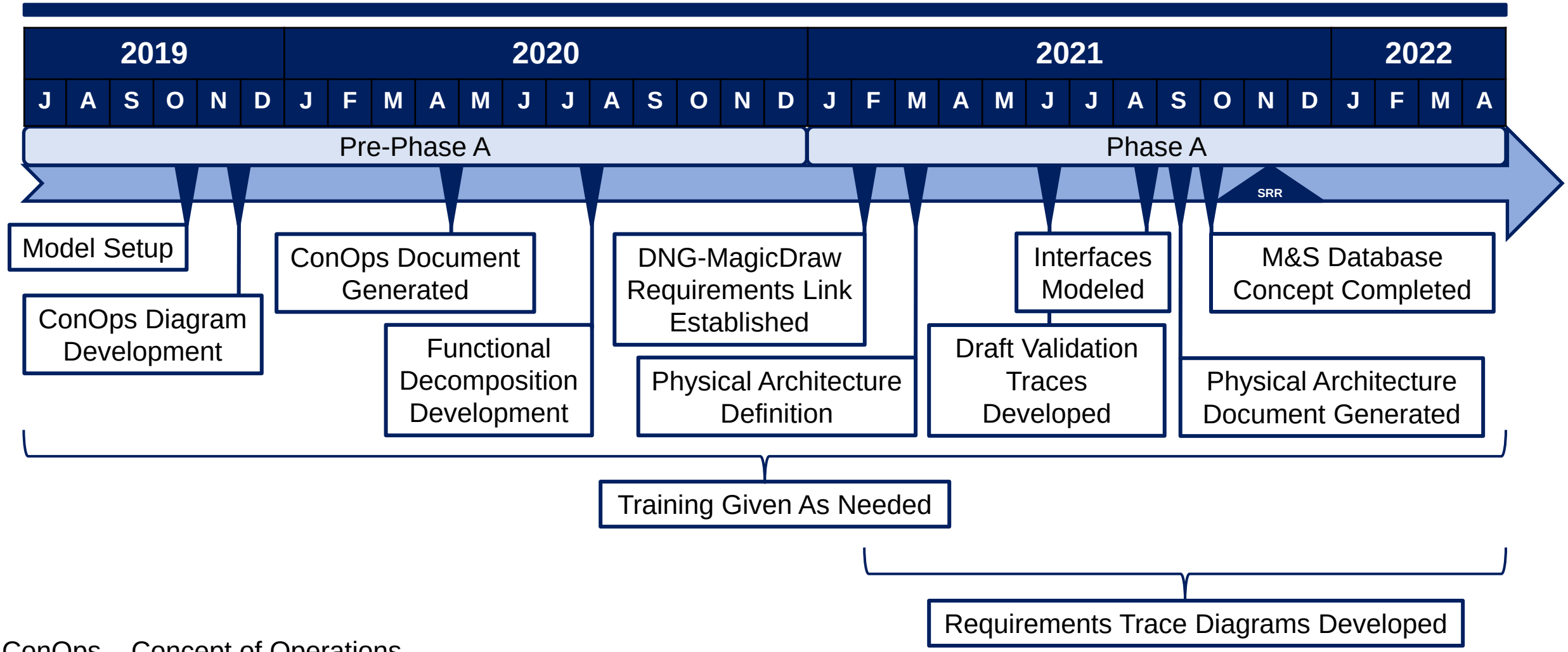
MAV Intro | MBSE Intro | MAV MBSE

Conclusions



- *Architecting Spacecraft with SysML, A Model-Based Systems Engineering Approach*, by Sanford Friedenthal and Christopher Oster. Friedenthal & Oster, 2017.

Conclusions – MBSE Over Time



ConOps – Concept of Operations
DNG – Doors Next Generation
M&S – Modeling & Simulation

MAV Intro	MBSE Intro	MAV MBSE

Lessons Learned

MBSE Takes Time

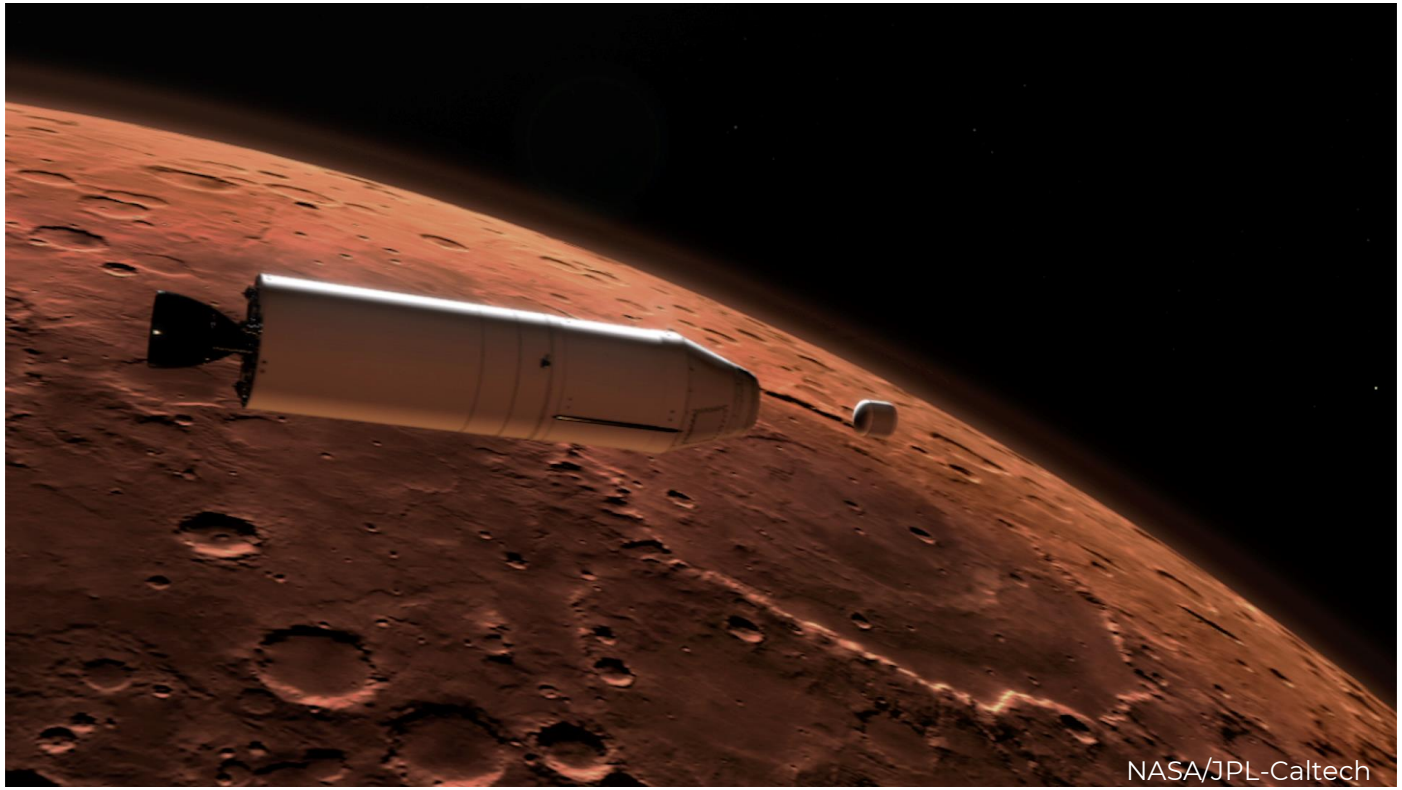
Avoid Work Duplication

Helpful Steps for New Modeling Applications

1. Identify modeling methods for application.
2. Identify relations to existing model information and weigh potential benefit.
3. Consider method/process for sharing information contained in the potential application.
4. Consider how to address baselining/configuration management and security needs.
5. Assess issues for the implementation and refine application details.
6. Obtain necessary approvals to implement modeling applications.
7. Implement modeling application and continue to refine as necessary.

Forward Work

- Human Factors & Flight Software artifact integration.
- Use model generated Interface Information to develop interface documents.
- Continue to implement MBSE as we progress through project lifecycle.

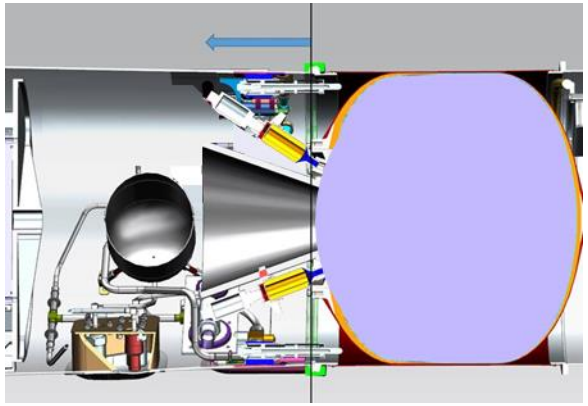


*Images notional and subject to change

Questions

BONUS – Trade Study!

Visibility Trade - Configurations Overview



Option 1: Extended S2 forward structure/aft skirt length

Option 2: Moveable shell

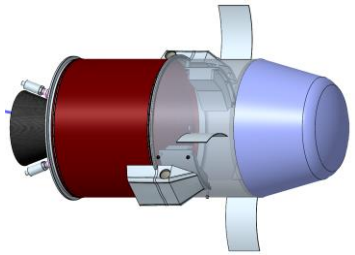
Option 3: Snap spring panels

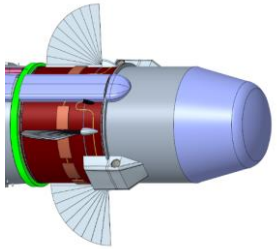
Option 4: Tritium/other paint/coatings

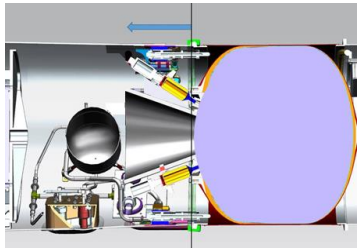
Option 5: Folded fan panels

*Images notional and subject to change

Unweighted Scoring





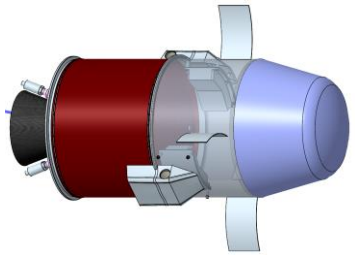


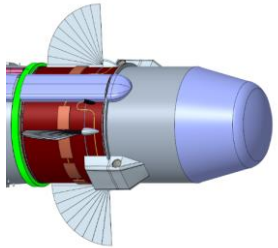
Option	High Albedo Paint	Spring Panels	Fan Panels	Extended 2nd Stage
Mass	3	2	1	2
Stowed Volume/OML	3	2	2	3
Complexity	3	2	2	3
Schedule	3	3	3	3
Cost	3	3	3	3
Safety	3	3	3	3
Reliability	5	4	4	5

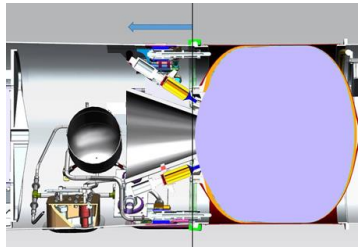
Score	1	2	3	4	5
Mass	<0.5kg added	<0.5g added	No change	<0.5kg subtracted	>0.5 kg subtracted
Stowed Volume/OML	Major increase in OML	Minor increase in OML	No change	Minor decrease in OML	Major decrease in OML
Complexity	Major increase in complexity	Minor increase in complexity	Small procedures added/ almost no change	Minor decrease in complexity	Major decrease in complexity
Schedule	Major delay, exceeding margin	Minor delay, within margin	Very minor delay/ no change	Minor improvement	Major improvement
Cost	Major cost increase	Minor cost increase	No change	Minor cost decrease	Major cost decrease
Safety	Will require range safety waivers	Will require tailoring of NASA-STDs	No change	Existing safety concerns reduced	Existing safety concerns eliminated
Reliability	TRL 1-2	TRL 3-4	TRL~5	TRL 6-7	TRL 8-9

*Images notional and subject to change

Weighted Scoring + Totals







Option	High Albedo Paint	Spring Panels	Fan Panels	Extended 2nd Stage
Mass	85.71	57.14	28.57	57.14
Stowed Volume/OML	71.43	47.62	47.62	71.43
Complexity	42.86	28.57	28.57	42.86
Schedule	14.29	14.29	14.29	14.29
Cost	14.29	14.29	14.29	14.29
Safety	28.57	28.57	28.57	28.57
Reliability	71.43	57.14	57.14	71.43
Total	329	248	219	300

*Images notional and subject to change